

AP Physics Multiple Choice Practice – Electrostatics

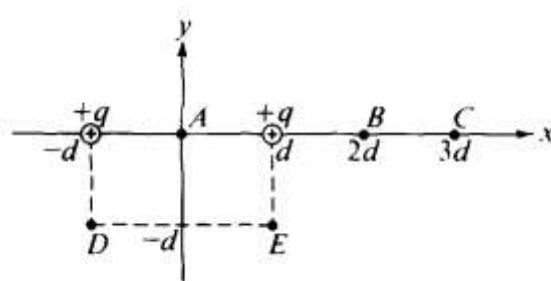
1. The electron volt is a measure of  
(A) charge (B) energy (C) impulse (D) momentum (E) velocity
2. A solid conducting sphere is given a positive charge  $Q$ . How is the charge  $Q$  distributed in or on the sphere?  
(A) It is concentrated at the center of the sphere.  
(B) It is uniformly distributed throughout the sphere.  
(C) Its density decreases radially outward from the center.  
(D) Its density increases radially outward from the center.  
(E) It is uniformly distributed on the surface of the sphere only.
3. A parallel-plate capacitor is charged by connection to a battery. If the battery is disconnected and the separation between the plates is increased, what will happen to the charge on the capacitor and the voltage across it?  
(A) Both remain fixed. (B) Both increase. (C) Both decrease.  
(D) The charge increases and the voltage decreases. (E) The charge remains fixed and the voltage increases.

Questions 4 – 5.

A point P is 0.50 meter from a point charge of  $5.0 \times 10^{-8}$  coulomb.

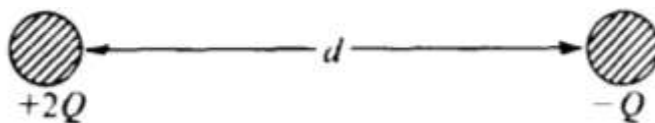
4. The intensity of the electric field at point P is most nearly  
(A)  $2.5 \times 10^{-8}$  N/C (B)  $2.5 \times 10^1$  N/C (C)  $9.0 \times 10^2$  N/C (D)  $1.8 \times 10^3$  N/C (E)  $7.5 \times 10^8$  N/C
5. The electric potential at point P is most nearly  
(A)  $2.5 \times 10^{-8}$  V (B)  $2.5 \times 10^1$  V (C)  $9.0 \times 10^2$  V (D)  $1.8 \times 10^3$  V (E)  $7.5 \times 10^3$  V
6. One joule of work is needed to move one coulomb of charge from one point to another with no change in velocity. Which of the following is true between the two points?  
(A) The resistance is one ohm. (B) The current is one ampere.  
(C) The potential difference is one volt. (D) The electric field strength is one newton per coulomb.  
(E) The electric field strength is one joule per electron.

Questions 7 – 8



Two positive charges of magnitude  $q$  are each a distance  $d$  from the origin  $A$  of a coordinate system as shown above.

7. At which of the following points is the electric field least in magnitude?  
(A) A (B) B (C) C (D) D (E) E
8. At which of the following points is the electric potential greatest in magnitude?  
(A) A (B) B (C) C (D) D (E) E
9. A parallel-plate capacitor has a capacitance  $C_0$ . A second parallel-plate capacitor has plates with twice the area and twice the separation. The capacitance of the second capacitor is most nearly  
(A)  $\frac{1}{4}C_0$  (B)  $\frac{1}{2}C_0$  (C)  $C_0$  (D)  $2C_0$  (E)  $4C_0$

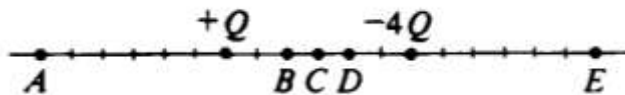


10. Two identical conducting spheres are charged to  $+2Q$  and  $-Q$ , respectively, and are separated by a distance  $d$  (much greater than the radii of the spheres) as shown above. The magnitude of the force of attraction on the left sphere is  $F_1$ . After the two spheres are made to touch and then are re-separated by distance  $d$ , the magnitude of the force on the left sphere is  $F_2$ . Which of the following relationships is correct?  
 (A)  $2F_1 = F_2$  (B)  $F_1 = F_2$  (C)  $F_1 = 2F_2$  (D)  $F_1 = 4F_2$  (E)  $F_1 = 8F_2$
11. The capacitance of a parallel-plate capacitor can be increased by increasing which of the following?  
 (A) The distance between the plates (B) The charge on each plate (C) The area of the plates  
 (D) The potential difference across the plates (E) None of the above
12. An electron volt is a measure of  
 (A) energy (B) electric field (C) electric potential due to one electron  
 (D) force per unit electron charge (E) electric charge

Questions 13 – 14

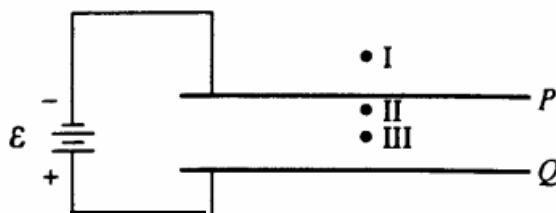
An electron is accelerated from rest for a time of  $10^{-9}$  second by a uniform electric field that exerts a force of  $8.0 \times 10^{-15}$  newton on the electron.

13. What is the magnitude of the electric field?  
 (A)  $8.0 \times 10^{-24}$  N/C (B)  $9.1 \times 10^{-22}$  N/C (C)  $8.0 \times 10^{-6}$  N/C (D)  $2.0 \times 10^{-5}$  N/C (E)  $5.0 \times 10^4$  N/C
14. The speed of the electron after it has accelerated for the  $10^{-9}$  second is most nearly  
 (A)  $10^1$  m/s (B)  $10^3$  m/s (C)  $10^5$  m/s (D)  $10^7$  m/s (E)  $10^9$  m/s
15. A hollow metal sphere of radius  $R$  is positively charged. Of the following distances from the center of the sphere, which location will have the greatest electric field strength?  
 (A) 0 (center of the sphere) (B)  $3R/2$  (C)  $5R/4$  (D)  $2R$   
 (E) None of the above because the field is of constant strength
16. Two isolated charges,  $+q$  and  $-2q$ , are 2 centimeters apart. If  $F$  is the magnitude of the force acting on charge  $-2q$ , what are the magnitude and direction of the force acting on charge  $+q$ ?
- | <u>Magnitude</u> | <u>Direction</u>       |
|------------------|------------------------|
| (A) $(1/2)F$     | Toward charge $-2q$    |
| (B) $2F$         | Away from charge $-2q$ |
| (C) $F$          | Toward charge $-2q$    |
| (D) $F$          | Away from charge $-2q$ |
| (E) $2F$         | Toward charge $-2q$    |

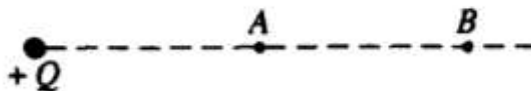


17. Charges  $+Q$  and  $-4Q$  are situated as shown above. The net electric field is zero nearest which point?  
 (A) A (B) B (C) C (D) D (E) E

18. A positive charge of  $10^{-6}$  coulomb is placed on an insulated solid conducting sphere. Which of the following is true?
- (A) The charge resides uniformly throughout the sphere.
  - (B) The electric field inside the sphere is constant in magnitude, but not zero.
  - (C) The electric field in the region surrounding the sphere increases with increasing distance from the sphere.
  - (D) An insulated metal object acquires a net positive charge when brought near to, but not in contact with, the sphere.
  - (E) When a second conducting sphere is connected by a conducting wire to the first sphere, charge is transferred until the electric potentials of the two spheres are equal.



19. Two large parallel conducting plates P and Q are connected to a battery of emf  $\mathcal{E}$ , as shown above. A test charge is placed successively at points I, II, and III. If edge effects are negligible, the force on the charge when it is at point III is
- (A) of equal magnitude and in the same direction as the force on the charge when it is at point I
  - (B) of equal magnitude and in the same direction as the force on the charge when it is at point II
  - (C) equal in magnitude to the force on the charge when it is at point I, but in the opposite direction
  - (D) much greater in magnitude than the force on the charge when it is at point II, but in the same direction
  - (E) much less in magnitude than the force on the charge when it is at point II, but in the same direction
20. Forces between two objects which are inversely proportional to the square of the distance between the objects include which of the following?
- I. Gravitational force between two celestial bodies
  - II. Electrostatic force between two electrons
  - III. Nuclear force between two neutrons
- (A) I only      (B) III only      (C) I and II only      (D) II and III only      (E) I, II, and III

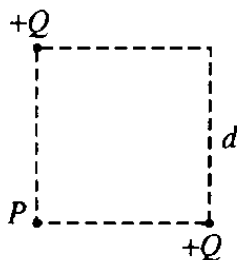


21. The diagram above shows an isolated, positive charge  $Q$ . Point (B) is twice as far away from  $Q$  as point A. The ratio of the electric field strength at point A to the electric field strength at point B is
- (A) 8 to 1      (B) 4 to 1      (C) 2 to 1      (D) 1 to 1      (E) 1 to 2
22. Which of the following is true about the net force on an uncharged conducting sphere in a uniform electric field?
- (A) It is zero.
  - (B) It is in the direction of the field.
  - (C) It is in the direction opposite to the field.
  - (D) It produces a torque on the sphere about the direction of the field.
  - (E) It causes the sphere to oscillate about an equilibrium position.



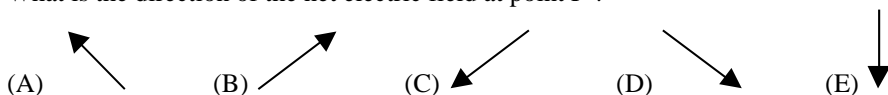
23. Two conducting spheres of different radii, as shown above, each have charge  $-Q$ . Which of the following occurs when the two spheres are connected with a conducting wire?
- (A) No charge flows.
  - (B) Negative charge flows from the larger sphere to the smaller sphere until the electric field at the surface of each sphere is the same.
  - (C) Negative charge flows from the larger sphere to the smaller sphere until the electric potential of each sphere is the same.
  - (D) Negative charge flows from the smaller sphere to the larger sphere until the electric field at the surface of each sphere is the same.
  - (E) Negative charge flows from the smaller sphere to the larger sphere until the electric potential of each sphere is the same.
24. Two parallel conducting plates are connected to a constant voltage source. The magnitude of the electric field between the plates is  $2,000 \text{ N/C}$ . If the voltage is doubled and the distance between the plates is reduced to  $1/5$  the original distance, the magnitude of the new electric field is
- (A)  $800 \text{ N/C}$       (B)  $1,600 \text{ N/C}$       (C)  $2,400 \text{ N/C}$       (D)  $5,000 \text{ N/C}$       (E)  $20,000 \text{ N/C}$

Questions 25 – 26



The figure above shows two particles, each with a charge of  $+Q$ , that are located at the opposite corners of a square of side  $d$ .

25. What is the direction of the net electric field at point P ?

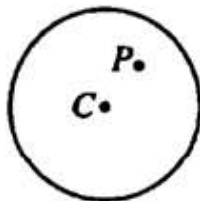


26. What is the potential energy of a particle of charge  $+q$  that is held at point P ?

(A) Zero      (B)  $\frac{\sqrt{2}}{4\pi\epsilon_0} \frac{qQ}{d}$       (C)  $\frac{1}{4\pi\epsilon_0} \frac{qQ}{d}$       (D)  $\frac{2}{4\pi\epsilon_0} \frac{qQ}{d}$       (E)  $\frac{2\sqrt{2}}{4\pi\epsilon_0} \frac{qQ}{d}$

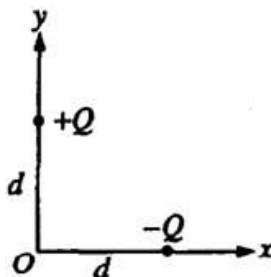
27. Two parallel conducting plates, separated by a distance  $d$ , are connected to a battery of emf  $\mathcal{E}$ . Which of the following is correct if the plate separation is doubled while the battery remains connected?
- (A) The electric charge on the plates is doubled.
  - (B) The electric charge on the plates is halved.
  - (C) The potential difference between the plates is doubled.
  - (D) The potential difference between the plates is halved.
  - (E) The capacitance is unchanged.

28. A  $4\ \mu\text{F}$  capacitor is charged to a potential difference of  $100\ \text{V}$ . The electrical energy stored in the capacitor is  
 (A)  $2 \times 10^{-10}\ \text{J}$  (B)  $2 \times 10^{-8}\ \text{J}$  (C)  $2 \times 10^{-6}\ \text{J}$  (D)  $2 \times 10^{-4}\ \text{J}$  (E)  $2 \times 10^{-2}\ \text{J}$



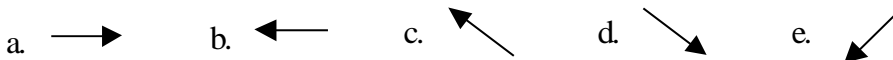
29. The hollow metal sphere shown above is positively charged. Point C is the center of the sphere and point P is any other point within the sphere. Which of the following is true of the electric field at these points?  
 (A) It is zero at both points.  
 (B) It is zero at C, but at P it is not zero and is directed inward.  
 (C) It is zero at C, but at P it is not zero and is directed outward.  
 (D) It is zero at P, but at C it is not zero.  
 (E) It is not zero at either point.

Questions 30 – 31



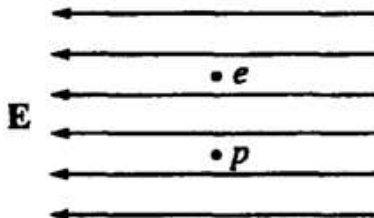
Charges  $-Q$  and  $+Q$  are located on the  $x$ - and  $y$ -axes, respectively, each at a distance  $d$  from the origin  $O$ , as shown above.

30. What is the direction of the electric field at the origin  $O$ ?



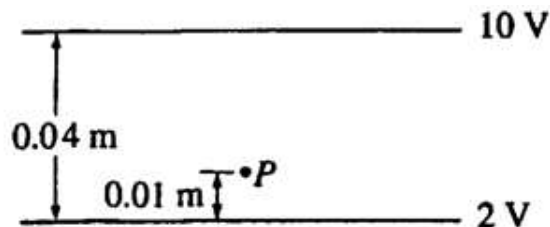
31. What is the magnitude of the electric field at the origin  $O$ ?

- (A)  $\frac{kQ}{2d^2}$  (B)  $\frac{kQ}{\sqrt{2}d^2}$  (C)  $\frac{kQ}{d^2}$  (D)  $\frac{\sqrt{2}kQ}{d^2}$  (E)  $\frac{2kQ}{d^2}$



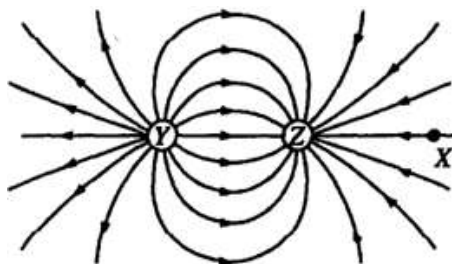
32. An electron  $e$  and a proton  $p$  are simultaneously released from rest in a uniform electric field  $E$ , as shown above. Assume that the particles are sufficiently far apart so that the only force acting on each particle after it is released is that due to the electric field. At a later time when the particles are still in the field, the electron and the proton will have the same  
 (A) direction of motion (B) speed (C) displacement (D) magnitude of acceleration  
 (E) magnitude of force acting on them

Questions 33 – 34

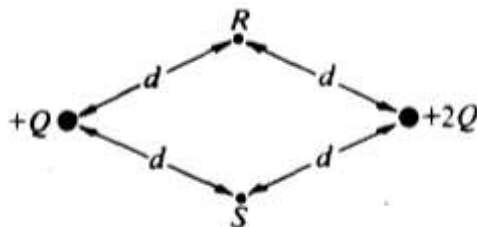


Two large, flat, parallel, conducting plates are 0.04 m apart, as shown above. The lower plate is at a potential of 2 V with respect to ground. The upper plate is at a potential of 10 V with respect to ground. Point  $P$  is located 0.01 m above the lower plate.

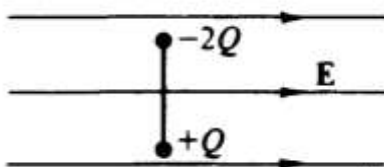
33. The electric potential at point  $P$  is  
 (A) 10 V (B) 8 V (C) 6 V (D) 4 V (E) 2 V
34. The magnitude of the electric field at point  $P$  is  
 (A) 800 V/m (B) 600 V/m (C) 400 V/m (D) 200 V/m (E) 100 V/m
35. A particle of charge  $Q$  and mass  $m$  is accelerated from rest through a potential difference  $V$ , attaining a kinetic energy  $K$ . What is the kinetic energy of a particle of charge  $2Q$  and mass  $m/2$  that is accelerated from rest through the same potential difference?  
 (A)  $\frac{1}{4}K$  (B)  $\frac{1}{2}K$  (C)  $K$  (D)  $2K$  (E)  $4K$



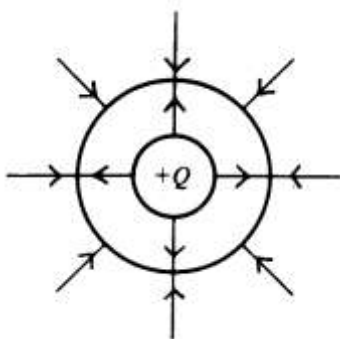
36. The diagram above shows electric field lines in an isolated region of space containing two small charged spheres,  $Y$  and  $Z$ . Which of the following statements is true?  
 (A) The charge on  $Y$  is negative and the charge on  $Z$  is positive.  
 (B) The strength of the electric field is the same everywhere.  
 (C) The electric field is strongest midway between  $Y$  and  $Z$ .  
 (D) A small negatively charged object placed at point  $X$  would tend to move toward the right.  
 (E) Both charged spheres  $Y$  and  $Z$  carry charge of the same sign.
37. A hollow metal sphere 1.0 m in diameter carries a charge of  $4.0 \mu\text{C}$ . The electric field at a distance of 2.0 m from the center of the sphere is most nearly  
 (A)  $9.0 \times 10^3 \text{ N/C}$  (B)  $1.8 \times 10^4 \text{ N/C}$  (C)  $2.4 \times 10^4 \text{ N/C}$  (D)  $3.6 \times 10^4 \text{ N/C}$  (E)  $1.4 \times 10^5 \text{ N/C}$
38. A parallel-plate capacitor has a capacitance  $C_0$ . A second parallel-plate capacitor has plates with twice the area and twice the separation. The capacitance of the second capacitor is most nearly  
 (A)  $\frac{1}{4}C_0$  (B)  $\frac{1}{2}C_0$  (C)  $C_0$  (D)  $2C_0$  (E)  $4C_0$
39. The electric field  $E$  just outside the surface of a charged conductor is  
 (A) directed perpendicular to the surface (B) directed parallel to the surface  
 (C) independent of the surface charge density (D) zero (E) infinite



40. Points R and S are each the same distance  $d$  from two unequal charges,  $+Q$  and  $+2Q$ , as shown above. The work required to move a charge  $-Q$  from point R to point S is
- (A) dependent on the path taken from R to S
  - (B) directly proportional to the distance between R and S
  - (C) positive
  - (D) zero
  - (E) negative



41. A rigid insulated rod, with two unequal charges attached to its ends, is placed in a uniform electric field  $E$  as shown above. The rod experiences a
- (A) net force to the left and a clockwise rotation
  - (B) net force to the left and a counterclockwise rotation
  - (C) net force to the right and a clockwise rotation
  - (D) net force to the right and a counterclockwise rotation
  - (E) rotation, but no net force

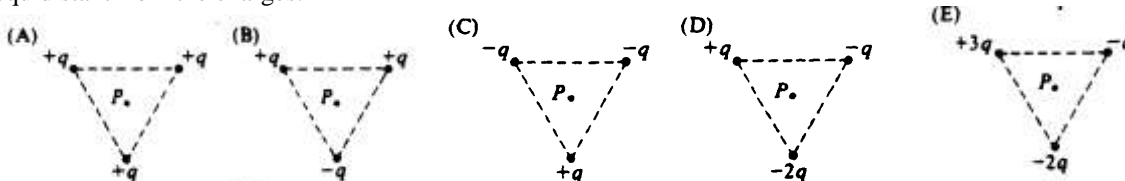


- \*42. The electric field of two long coaxial cylinders is represented by lines of force as shown above. The charge on the inner cylinder is  $+Q$ . The charge on the outer cylinder is
- (A)  $+3Q$
  - (B)  $+Q$
  - (C)  $0$
  - (D)  $-Q$
  - (E)  $-3Q$
43. An isolated capacitor with air between its plates has a potential difference  $V_0$  and a charge  $Q_0$ . After the space between the plates is filled with oil, the difference in potential is  $V$  and the charge is  $Q$ . Which of the following pairs of relationships is correct?
- (A)  $Q = Q_0$  and  $V > V_0$
  - (B)  $Q = Q_0$  and  $V < V_0$
  - (C)  $Q > Q_0$  and  $V = V_0$
  - (D)  $Q < Q_0$  and  $V < V_0$
  - (E)  $Q > Q_0$  and  $V > V_0$

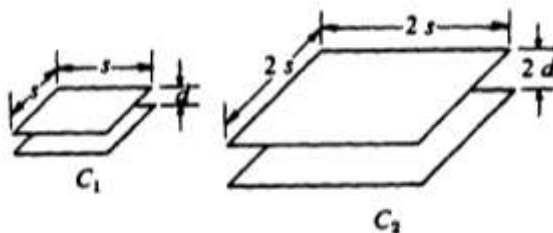
44. Two small spheres have equal charges  $q$  and are separated by a distance  $d$ . The force exerted on each sphere by the other has magnitude  $F$ . If the charge on each sphere is doubled and  $d$  is halved, the force on each sphere has magnitude  
 (A)  $F$  (B)  $2F$  (C)  $4F$  (D)  $8F$  (E)  $16F$
45. Which of the following statements about conductors under electrostatic conditions is true?  
 (A) Positive work is required to move a positive charge over the surface of a conductor.  
 (B) Charge that is placed on the surface of a conductor always spreads evenly over the surface.  
 (C) The electric potential inside a conductor is always zero.  
 (D) The electric field at the surface of a conductor is tangent to the surface.  
 (E) The surface of a conductor is always an equipotential surface.
46. A charged particle traveling with a velocity  $v$  in an electric field  $E$  experiences a force  $F$  that must be  
 (A) parallel to  $v$  (B) perpendicular to  $v$  (C) perpendicular to  $v$  and  $E$  (D) parallel to  $E$  (E) perpendicular to  $E$
47. A positive charge of  $3.0 \times 10^{-8}$  coulomb is placed in an upward directed uniform electric field of  $4.0 \times 10^4$  N/C. When the charge is moved 0.5 meter upward, the work done by the electric force on the charge is  
 (A)  $6 \times 10^{-4}$  J (B)  $12 \times 10^{-4}$  J (C)  $2 \times 10^4$  J (D)  $8 \times 10^4$  J (E)  $12 \times 10^4$  J

Questions 48 – 49

The following configurations of electric charges are located at the vertices of an equilateral triangle. Point  $P$  is equidistant from the charges.

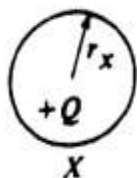


48. In which configuration is the electric field at  $P$  equal to zero?  
 (A) A (B) B (C) C (D) D (E) E
49. In which configuration is the electric field at  $P$  pointed at the midpoint between two of the charges?  
 (A) A (B) B (C) C (D) D (E) E



50. Two square parallel-plate capacitors of capacitances  $C_1$  and  $C_2$  have the dimensions shown in the diagrams above. The ratio of  $C_1$  to  $C_2$  is  
 (A) 1 to 4 (B) 1 to 2 (C) 1 to 1 (D) 2 to 1 (E) 4 to 1
51. A sheet of mica is inserted between the plates of an isolated charged parallel-plate capacitor. Which of the following statements is true?  
 (A) The capacitance decreases.  
 (B) The potential difference across the capacitor decreases.  
 (C) The energy of the capacitor does not change.  
 (D) The charge on the capacitor plates decreases  
 (E) The electric field between the capacitor plates increases.





52. Two conducting spheres, X and Y have the same positive charge  $+Q$ , but different radii ( $r_x > r_y$ ) as shown above. The spheres are separated so that the distance between them is large compared with either radius. If a wire is connected between them, in which direction will electrons be directed in the wire?
- (A) From X to Y  
 (B) From Y to X  
 (C) There will be no flow of charge in the wire.  
 (D) It cannot be determined without knowing the magnitude of  $Q$ .  
 (E) It cannot be determined without knowing whether the spheres are solid or hollow.

Questions 53 – 54

A sphere of radius  $R$  has positive charge  $Q$  uniformly distributed on its surface

53. Which of the following represents the magnitude of the electric field  $E$  and the potential  $V$  as functions of  $r$ , the distance from the center of the sphere, when  $r < R$  ?

$E$	$V$
(A) 0	$kQ/R$
(B) 0	$kQ/r$
(C) 0	0
(D) $kQ/r^2$	0
(E) $kQ/R^2$	0

54. Which of the following represents the magnitude, of the electric field  $E$  and the potential  $V$  as functions of  $r$ , the distance from the center of sphere, when  $r > R$  ?

$E$	$V$
(A) $kQ/R^2$	$kQ/R$
(B) $kQ/R$	$kQ/R$
(C) $kQ/R$	$kQ/r$
(D) $kQ/r^2$	$kQ/r$
(E) $kQ/r^2$	$kQ/r^2$

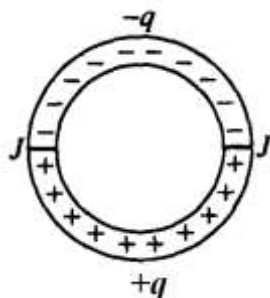
55. From the electric field vector at a point, one can determine which of the following?

- I. The direction of the electrostatic force on a test charge of known sign at that point  
 II. The magnitude of the electrostatic force exerted per unit charge on a test charge at that point  
 III. The electrostatic charge at that point

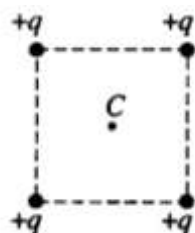
(A) I only    (B) III only    (C) I and II only    (D) II and III only    (E) I, II, and III

56. A conducting sphere of radius  $R$  carries a charge  $Q$ . Another conducting sphere has a radius  $R/2$ , but carries the same charge. The spheres are far apart. The ratio of the electric field near the surface of the smaller sphere to the field near the surface of the larger sphere is most nearly

(A)  $1/4$     (B)  $1/2$     (C) 1    (D) 2    (E) 4

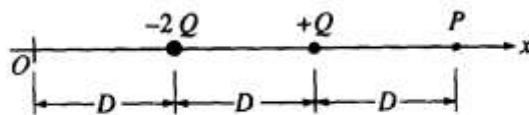


57. A circular ring made of an insulating material is cut in half. One half is given a charge  $-q$  uniformly distributed along its arc. The other half is given a charge  $+q$  also uniformly distributed along its arc. The two halves are then rejoined with insulation at the junctions J, as shown above. If there is no change in the charge distributions, what is the direction of the net electrostatic force on an electron located at the center of the circle?
- (A) Toward the top of the page (B) Toward the bottom of the page (C) To the right (D) To the left (E) Into the page.

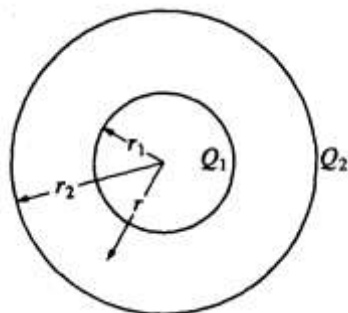


58. Four positive charges of magnitude  $q$  are arranged at the corners of a square, as shown above. At the center C of the square, the potential due to one charge alone is  $V_0$  and the electric field due to one charge alone has magnitude  $E_0$ . Which of the following correctly gives the electric potential and the magnitude of the electric field at the center of the square due to all four charges?

	<u>Electric Potential</u>	<u>Electric Field</u>
(A)	Zero	Zero
(B)	Zero	$2E_0$
(C)	$2V_0$	$4E_0$
(D)	$4V_0$	Zero
(E)	$4V_0$	$2E_0$



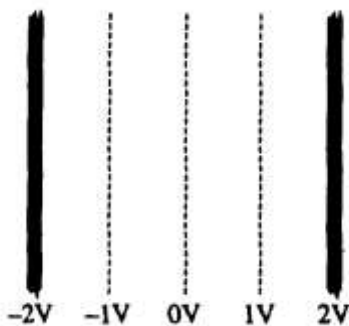
59. Two charges,  $-2Q$  and  $+Q$ , are located on the  $x$ -axis, as shown above. Point P, at a distance of  $3D$  from the origin O, is one of two points on the positive  $x$ -axis at which the electric potential is zero. How far from the origin O is the other point?
- (A)  $\frac{2}{3}D$  (B)  $D$  (C)  $\frac{3}{2}D$  (D)  $\frac{5}{3}D$  (E)  $2D$



\*60. Two concentric, spherical conducting shells have radii  $r_1$  and  $r_2$  and charges  $Q_1$  and  $Q_2$ , as shown above. Let  $r$  be the distance from the center of the spheres and consider the region  $r_1 < r < r_2$ . In this region the electric field is proportional to

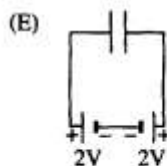
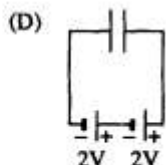
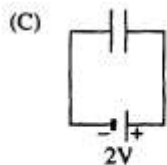
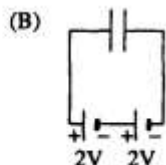
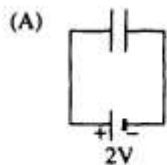
- (A)  $Q_1/r^2$  (B)  $(Q_1 + Q_2)/r^2$  (C)  $(Q_1 + Q_2)/r$  (D)  $Q_1/r_1 + Q_2/r$  (E)  $Q_1/r + Q_2/r_2$

Questions 61 – 62

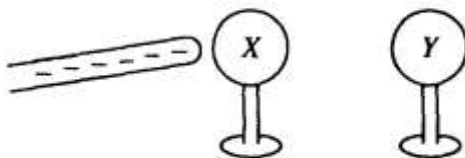


A battery or batteries connected to two parallel plates produce the equipotential lines between the plates shown above.

\*61. Which of the following configurations is most likely to produce these equipotential lines?



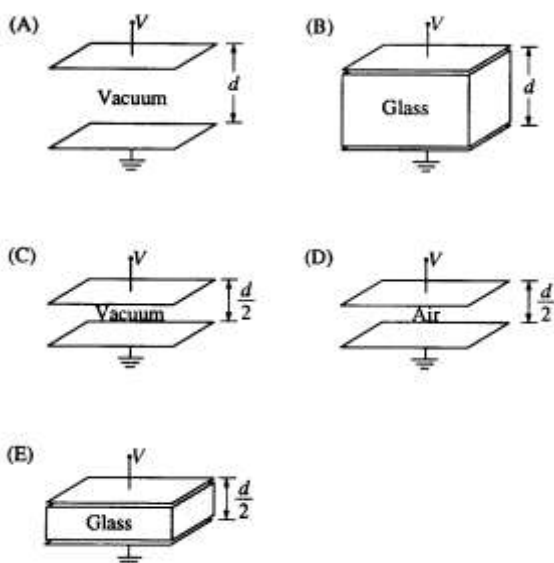
- \*62. The force on an electron located on the 0 volt potential line is  
 (A) 0 N (B) 1 N, directed to the right (C) 1 N, directed to the left  
 (D) to the right, but its magnitude cannot be determined without knowing the distance between the lines  
 (E) to the left, but its magnitude cannot be determined without knowing the distance between the lines



63. Two metal spheres that are initially uncharged are mounted on insulating stands, as shown above. A negatively charged rubber rod is brought close to, but does not make contact with, sphere X. Sphere Y is then brought close to X on the side opposite to the rubber rod. Y is allowed to touch X and then is removed some distance away. The rubber rod is then moved far away from X and Y. What are the final charges on the spheres?

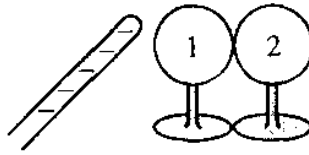
<u>Sphere X</u>	<u>Sphere Y</u>
A) Zero	Zero
B) Negative	Negative
C) Negative	Positive
D) Positive	Negative
E) Positive	Positive

64. Which of the following capacitors, each of which has plates of area  $A$ , would store the most charge on the top plate for a given potential difference  $V$ ?



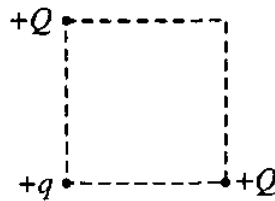
65. A parallel-plate capacitor has charge  $+Q$  on one plate and charge  $-Q$  on the other. The plates, each of area  $A$ , are a distance  $d$  apart and are separated by a vacuum. A single proton of charge  $+e$ , released from rest at the surface of the positively charged plate, will arrive at the other plate with kinetic energy proportional to


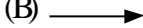



(A)  $\frac{edQ}{A}$  (B)  $\frac{Q^2}{eAd}$  (C)  $\frac{AeQ}{d}$  (D)  $\frac{Q}{ed}$  (E)  $\frac{eQ}{Ad}$



66. Two initially uncharged conductors, 1 and 2, are mounted on insulating stands and are in contact, as shown above. A negatively charged rod is brought near but does not touch them. With the rod held in place, conductor 2 is moved to the right by pushing its stand, so that the conductors are separated. Which of the following is now true of conductor 2?
- (A) It is uncharged. (B) It is positively charged. (C) It is negatively charged.  
 (D) It is charged, but its sign cannot be predicted.  
 (E) It is at the same potential that it was before the charged rod was brought near.

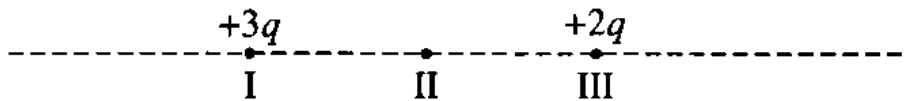
Questions 67 – 68



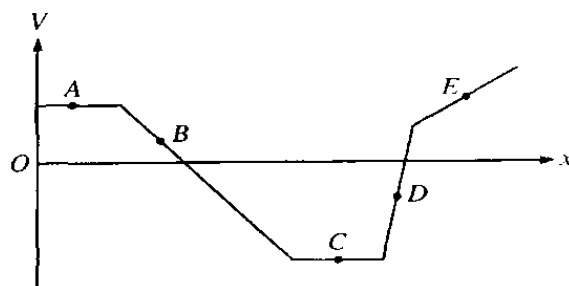
67. As shown above, two particles, each of charge  $+Q$ , are fixed at opposite corners of a square that lies in the plane of the page. A positive test charge  $+q$  is placed at a third corner. What is the direction of the force on the test charge due to the two other charges?
- (A)  (B)  (C)  (D)  (E) 
68. If  $F$  is the magnitude of the force on the test charge due to only one of the other charges, what is the magnitude of the net force acting on the test charge due to both of these charges?
- (A) Zero (B)  $\frac{F}{\sqrt{2}}$  (C)  $F$  (D)  $\sqrt{2}F$  (E)  $2$

Questions 69 – 70

Two charges are located on the line shown in the figure below, in which the charge at point I is  $+3q$  and the charge at point III is  $+2q$ . Point II is halfway between points I and III.



69. Other than at infinity, the electric field strength is zero at a point on the line in which of the following ranges?
- (A) To the left of I (B) Between I and II (C) Between II and III (D) To the right of III  
 (E) None; the field is zero only at infinity.
70. The electric potential is negative at some points on the line in which of the following ranges?
- (A) To the left of I (B) Between I and II (C) Between II and III (D) To the right of III  
 (E) None; this potential is never negative.
71. The work that must be done by an external agent to move a point charge of  $2 \text{ mC}$  from the origin to a point  $3 \text{ m}$  away is  $5 \text{ J}$ . What is the potential difference between the two points?
- (A)  $4 \times 10^{-4} \text{ V}$  (B)  $10^{-2} \text{ V}$  (C)  $2.5 \times 10^3 \text{ V}$  (D)  $2 \times 10^6 \text{ V}$  (E)  $6 \times 10^6 \text{ V}$



\*72. The graph above shows the electric potential  $V$  in a region of space as a function of position along the  $x$ -axis. At which point would a charged particle experience the force of greatest magnitude?

- (A) A (B) B (C) C (D) D (E) E:

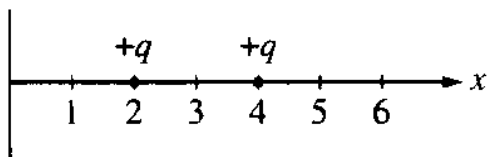
\*73. Suppose that an electron (charge  $-e$ ) could orbit a proton (charge  $+e$ ) in a circular orbit of constant radius  $R$ .

Assuming that the proton is stationary and only electrostatic forces act on the particles, which of the following represents the kinetic energy of the two-particle system?

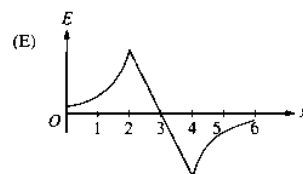
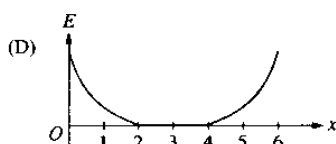
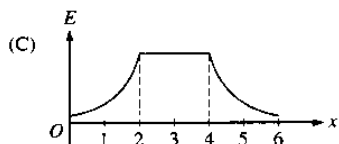
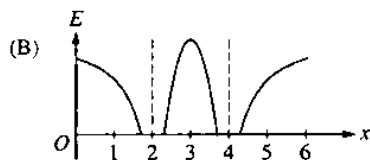
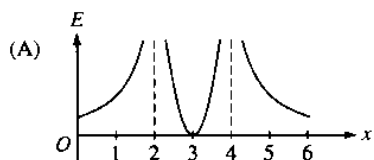
- (A)  $\frac{1}{4\pi\epsilon_0} \frac{e}{R}$  (B)  $\frac{1}{8\pi\epsilon_0} \frac{e^2}{R}$  (C)  $-\frac{1}{8\pi\epsilon_0} \frac{e^2}{R}$  (D)  $\frac{1}{4\pi\epsilon_0} \frac{e^2}{R^2}$  (E)  $-\frac{1}{4\pi\epsilon_0} \frac{e^2}{R^2}$

74. If the only force acting on an electron is due to a uniform electric field, the electron moves with constant

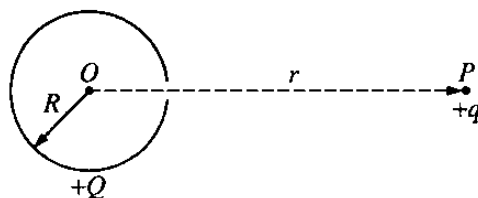
- (A) acceleration in a direction opposite to that of the field  
(B) acceleration in the direction of the field  
(C) acceleration in a direction perpendicular to that of the field  
(D) speed in a direction opposite to that of the field  
(E) speed in the direction of the field



75. Two charged particles, each with a charge of  $+q$ , are located along the  $x$ -axis at  $x=2$  and  $x=4$ , as shown above. Which of the following shows the graph of the magnitude of the electric field along the  $x$ -axis from the origin to  $x=6$ ?



76. A positive electric charge is moved at a constant speed between two locations in an electric field, with no work done by or against the field at any time during the motion. This situation can occur only if the
- (A) charge is moved in the direction of the field
  - (B) charge is moved opposite to the direction of the field
  - (C) charge is moved perpendicular to an equipotential line
  - (D) charge is moved along an equipotential line
  - (E) electric field is uniform

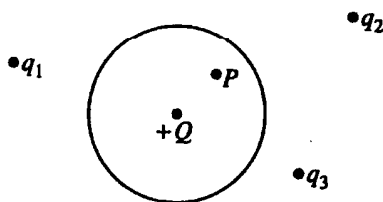


77. The nonconducting hollow sphere of radius  $R$  shown above carries a large charge  $+Q$ , which is uniformly distributed on its surface. There is a small hole in the sphere. A small charge  $+q$  is initially located at point  $P$ , a distance  $r$  from the center of the sphere. If  $k = 1/4\pi\epsilon_0$ , what is the work that must be done by an external agent in moving the charge  $+q$  from  $P$  through the hole to the center  $O$  of the sphere?
- (A) Zero
  - (B)  $kqQ/r$
  - (C)  $kqQ/R$
  - (D)  $kq(Q - q)/r$
  - (E)  $kqQ(1/R - 1/r)$

#### Questions 78 – 79

A capacitor is constructed of two identical conducting plates parallel to each other and separated by a distance  $d$ . The capacitor is charged to a potential difference of  $V_0$  by a battery, which is then disconnected.

78. If any edge effects are negligible, what is the magnitude of the electric field between the plates?
- (A)  $V_0 d$
  - (B)  $V_0/d$
  - (C)  $d/V_0$
  - (D)  $V_0/d^2$
  - (E)  $V_0^2/d$
79. A sheet of insulating plastic material is inserted between the plates without otherwise disturbing the system. What effect does this have on the capacitance?
- (A) It causes the capacitance to increase.
  - (B) It causes the capacitance to decrease.
  - (C) None; the capacitance does not change.
  - (D) Nothing can be said about the effect without knowing the dielectric constant of the plastic.
  - (E) Nothing can be said about the effect without knowing the thickness of the sheet.

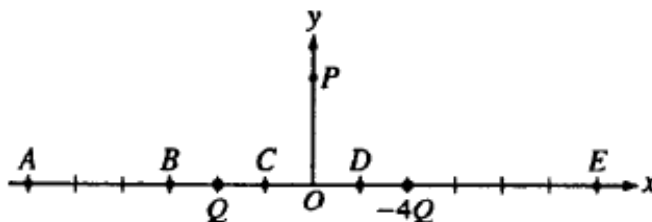


- \*80. A point charge  $+Q$  is inside an uncharged conducting spherical shell that in turn is near several isolated point charges, as shown above. The electric field at point  $P$  inside the shell depends on the magnitude of
- (A)  $Q$  only
  - (B) the charge distribution on the sphere only
  - (C)  $Q$  and the charge distribution on the sphere
  - (D) all of the point charges
  - (E) all of the point charges and the charge distribution on the sphere
81. A  $20\ \mu\text{F}$  parallel-plate capacitor is fully charged to  $30\ \text{V}$ . The energy stored in the capacitor is most nearly
- (A)  $9 \times 10^3\ \text{J}$
  - (B)  $9 \times 10^{-3}\ \text{J}$
  - (C)  $6 \times 10^{-4}\ \text{J}$
  - (D)  $2 \times 10^{-4}\ \text{J}$
  - (E)  $2 \times 10^{-7}\ \text{J}$

82. A potential difference  $V$  is maintained between two large, parallel conducting plates. An electron starts from rest on the surface of one plate and accelerates toward the other. Its speed as it reaches the second plate is proportional to

(A)  $1/V$  (B)  $\frac{1}{\sqrt{V}}$  (C)  $\sqrt{V}$  (D)  $V$  (E)  $V^2$

Questions 83 – 84



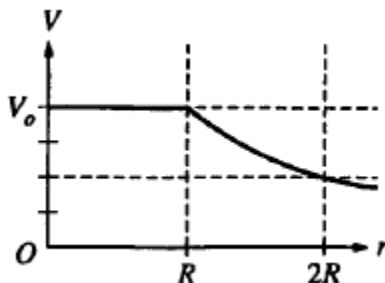
Particles of charge  $Q$  and  $-4Q$  are located on the  $x$ -axis as shown in the figure above. Assume the particles are isolated from all other charges.

83. Which of the following describes the direction of the electric field at point P?

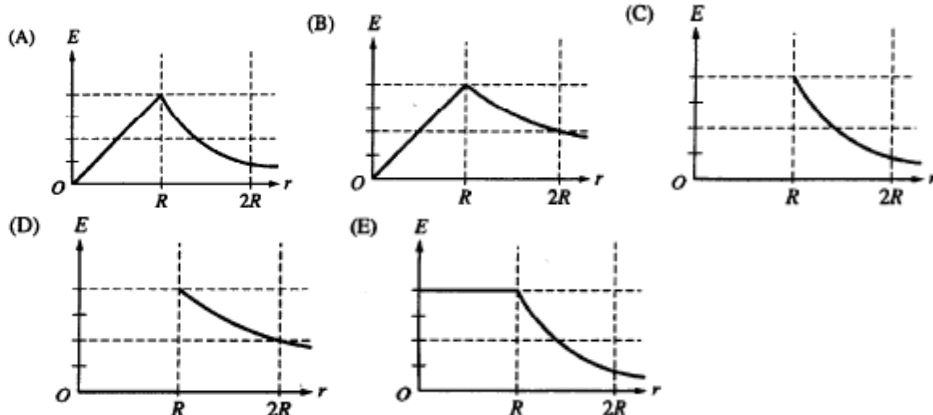
(A)  $+x$  (B)  $+y$  (C)  $-y$   
 (D) Components in both the  $-x$  and  $+y$  directions  
 (E) Components in both the  $+x$  and  $-y$  directions

84. At which of the labeled points on the  $x$ -axis is the electric field zero?

(A) A (B) B (C) C (D) D (E) E

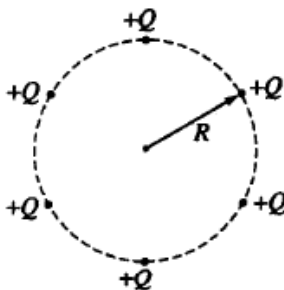


85. A solid metallic sphere of radius  $R$  has charge  $Q$  uniformly distributed on its outer surface. A graph of electric potential  $V$  as a function of position  $r$  is shown above. Which of the following graphs best represents the magnitude of the electric field  $E$  as a function of position  $r$  for this sphere?





Questions 86 – 87



As shown in the figure above, six particles, each with charge  $+Q$ , are held fixed and are equally spaced around the circumference of a circle of radius  $R$ .

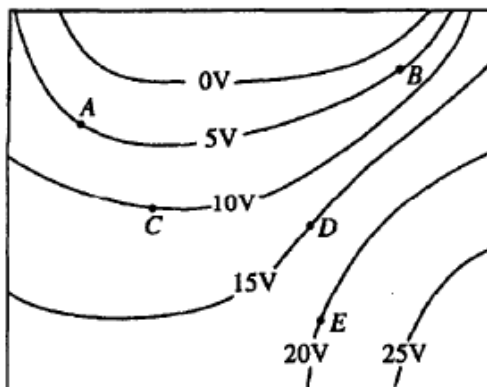
86. What is the magnitude of the resultant electric field at the center of the circle?

- (A) 0      (B)  $\frac{\sqrt{6}}{4\pi\epsilon_0} \frac{Q}{R^2}$       (C)  $\frac{2\sqrt{3}}{4\pi\epsilon_0} \frac{Q}{R^2}$       (D)  $\frac{3\sqrt{2}}{4\pi\epsilon_0} \frac{Q}{R^2}$       (E)  $\frac{3}{2\pi\epsilon_0} \frac{Q}{R^2}$

87. With the six particles held fixed, how much work would be required to bring a seventh particle of charge  $+Q$  from very far away and place it at the center of the circle?

- (A) 0      (B)  $\frac{\sqrt{6}}{4\pi\epsilon_0} \frac{Q}{R}$       (C)  $\frac{3}{2\pi\epsilon_0} \frac{Q^2}{R^2}$       (D)  $\frac{3}{2\pi\epsilon_0} \frac{Q^2}{R}$       (E)  $\frac{9}{\pi\epsilon_0} \frac{Q^2}{R}$

Questions 88 – 90



The diagram above shows equipotential lines produced by an unknown charge distribution. A, B, C, D, and E are points in the plane.

88. Which vector below best describes the direction of the electric field at point A ?

- (A)      (B)   
 (C)      (D)

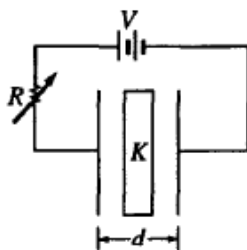
(E) None of these; the field is zero.

89. At which point does the electric field have the greatest magnitude?

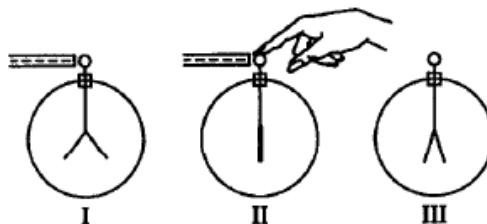
- (A) A      (B) B      (C) C      (D) D      (E) E

90. How much net work must be done by an external force to move a  $-1 \mu\text{C}$  point charge from rest at point C to rest at point E ?

- (A)  $-20 \mu\text{J}$       (B)  $-10 \mu\text{J}$       (C)  $10 \mu\text{J}$       (D)  $20 \mu\text{J}$       (E)  $30 \mu\text{J}$

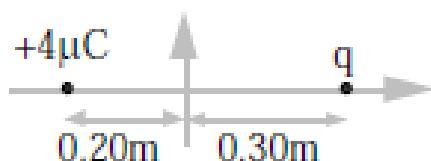


91. The plates of a parallel-plate capacitor of cross sectional area  $A$  are separated by a distance  $d$ , as shown above. Between the plates is a dielectric material of constant  $K$ . The plates are connected in series with a variable resistance  $R$  and a power supply of potential difference  $V$ . The capacitance  $C$  of this capacitor will increase if which of the following is decreased?
- (A)  $A$       (B)  $R$       (C)  $K$       (D)  $d$       (E)  $V$
92. A physics problem starts: "A solid sphere has charge distributed uniformly throughout. . . ." It may be correctly concluded that the
- (A) electric field is zero everywhere inside the sphere  
 (B) electric field inside the sphere is the same as the electric field outside  
 (C) electric potential on the surface of the sphere is not constant  
 (D) electric potential in the center of the sphere is zero  
 (E) sphere is not made of metal
- \*93. A uniform spherical charge distribution has radius  $R$ . Which of the following is true of the electric field strength due to this charge distribution at a distance  $r$  from the center of the charge?
- (A) It is greatest when  $r = 0$ .  
 (B) It is greatest when  $r = R/2$ .  
 (C) It is directly proportional to  $r$  when  $r > R$ .  
 (D) It is directly proportional to  $r$  when  $r < R$ .  
 (E) It is directly proportional to  $r^2$ .



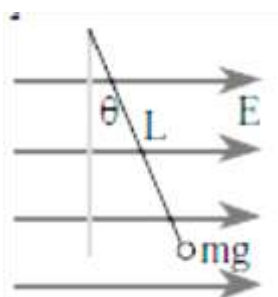
94. When a negatively charged rod is brought near, but does not touch, the initially uncharged electroscope shown above, the leaves spring apart (I). When the electroscope is then touched with a finger, the leaves collapse (II). When next the finger and finally the rod are removed, the leaves spring apart a second time (III). The charge on the leaves is
- (A) positive in both I and III  
 (B) negative in both I and III  
 (C) positive in I, negative in III  
 (D) negative in I, positive in III  
 (E) impossible to determine in either I or III
95. A positively charged conductor attracts a second object. Which of the following statements *could* be true?
- I. The second object is a conductor with negative net charge.  
 II. The second object is a conductor with zero net charge.  
 III. The second object is an insulator with zero net charge..
- (A) I only    (B) II only    (C) III only    (D) I & II only    (E) I, II & III

Questions 96 – 97

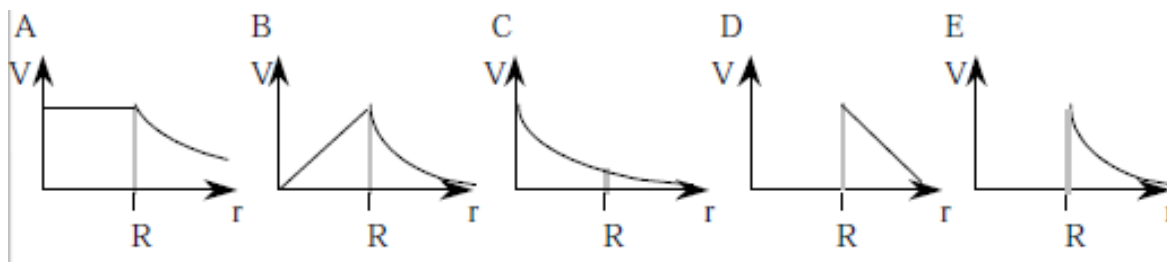


A point charge of  $+4.0 \mu\text{C}$  is placed on the negative x-axis  $0.20 \text{ m}$  to the left of the origin, as shown in the accompanying figure. A second point charge  $q$  is placed on the positive x-axis  $0.30 \text{ m}$  to the right of the origin.

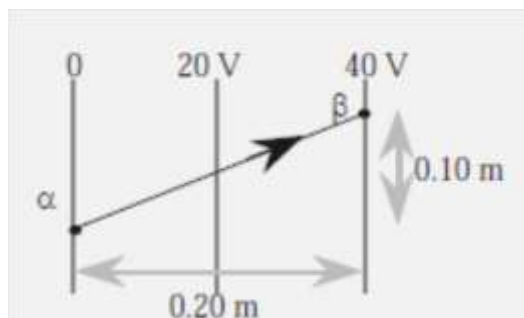
96. If the net electric field at the origin is zero. What is  $q$ ?  
 (A)  $+9.0 \mu\text{C}$  (B)  $+6.0 \mu\text{C}$  (C)  $0$  (D)  $-6.0 \mu\text{C}$  (E)  $-9.0 \mu\text{C}$
97. If the net electric potential at the origin is zero, what is  $q$ ?  
 (A)  $+9.0 \mu\text{C}$  (B)  $+6.0 \mu\text{C}$  (C)  $0$  (D)  $-6.0 \mu\text{C}$  (E)  $-9.0 \mu\text{C}$
98. Which of the following statements about solid conductors in electrostatics are true?  
 I. The electric field inside the conductor is always zero.  
 II. The electric potential inside the conductor is always zero.  
 III. Any net charge is on the surface.  
 (A) I only (B) II only (C) III only (D) I & III only (E) II & III only



99. A small object with charge  $q$  and weight  $mg$  is attached to one end of a string of length  $L$ . The other end is attached to a stationary support. The system is placed in a uniform horizontal electric field  $E$ , as shown in the accompanying figure. In the presence of the field, the string makes a constant angle  $\theta$  with the vertical. What is the sign and magnitude of  $q$ ?  
 (A) positive with magnitude  $\frac{mg}{E}$  (B) positive with magnitude  $\frac{mg}{E} \tan \theta$   
 (C) negative with magnitude  $\frac{mg}{E}$  (D) negative with magnitude  $\frac{mg}{E} \tan \theta$   
 (E) negative with magnitude  $\frac{E}{mg} \tan \theta$
100. An isolated conducting sphere of radius  $R$  has positive charge  $+Q$ . Which graph best depicts the electric potential as a function of  $r$ , the distance from the center of the sphere?

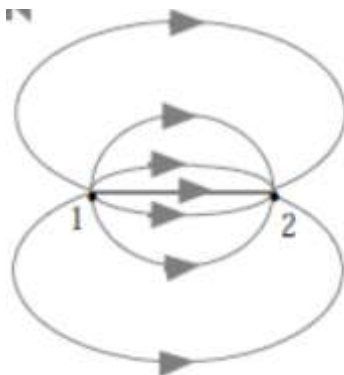
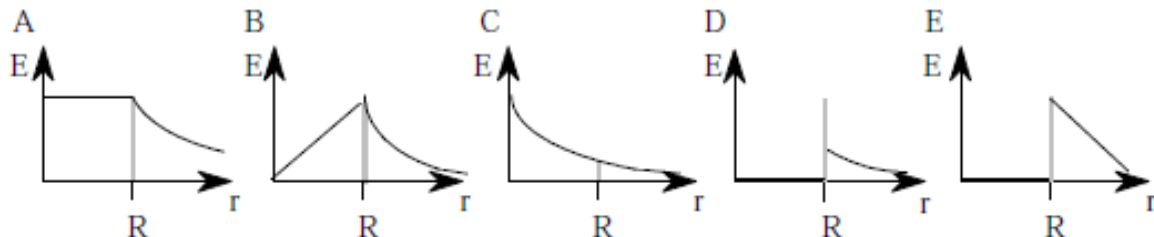


101. Two large parallel plates a distance  $d$  apart are charged by connecting them to a battery of potential difference  $V$ . The battery is disconnected, and the plates are slowly moved apart. As the distance between plates increases:
- (A) the charge on the plates decreases.
  - (B) the electric field intensity between the plates increases.
  - (C) the electric field intensity between the plates decreases.
  - (D) the potential difference between the plates decreases.
  - (E) the potential difference between the plates increases.

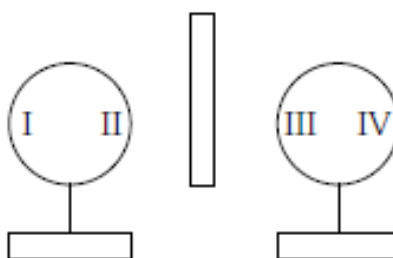


102. In the figure to the right, equipotential lines are drawn at 0, 20.0 V, and 40.0 V. The total work done in moving a point charge of  $+3.00$  mC from position a to position b is:
- (A) 4.00 mJ (B) 8.00 mJ (C) 12.0 mJ (D) 24.0 mJ (E) 120 mJ
103. Two positive point charges repel each other with force 0.36 N when their separation is 1.5 m. What force do they exert on each other when their separation is 1.0 m?
- (A) 0.81 N (B) 0.54 N (C) 0.36 N (D) 0.24 N (E) 0.16 N
- \*104. An amber rod is given a net negative charge and held at rest. Which of the following statements is true?
- (A) The amber rod is surrounded only by a magnetic field that circles the rod.
  - (B) The amber rod is surrounded only by an electric field that is directed out from the rod.
  - (C) The amber rod is surrounded only by an electric field that is directed into the rod.
  - (D) The amber rod is surrounded by both a magnetic field that circles the rod and an electric field that is directed out from the rod.
  - (E) The amber rod is surrounded by both a magnetic field that circles the rod and an electric field that is directed into the rod.
105. Two isolated conducting spheres ( $S_1$  of radius 0.030 m and initial charge  $+6.0$  nC and  $S_2$  of radius 0.040 m and initial charge  $+2.0$  nC) are connected by a conducting wire. Charge will flow in the wire until:
- (A) both spheres are equally charged.
  - (B) the net charge is zero.
  - (C) the force of repulsion between the two spheres becomes equal.
  - (D) both spheres have the same surface charge density.
  - (E) both spheres are at the same potential.
106. A point charge  $+q$  is placed midway between two point charges  $+3q$  and  $-q$  separated by a distance  $2d$ . If Coulomb's constant is  $k$ , the magnitude of the force on the charge  $+q$  is:
- A.  $2\frac{kq^2}{d^2}$       B.  $4\frac{kq^2}{d^2}$       C.  $6\frac{kq^2}{d^2}$       D.  $8\frac{kq^2}{d^2}$       E.  $10\frac{kq^2}{d^2}$
107. How much work is required to move  $-24$  mC of charge 4.0 m parallel to a uniform 6.0 N/C electric field?
- (A) 1.0 mJ (B) 16 mJ (C) 36 mJ (D) 62 mJ (E) 576 mJ

108. An isolated conducting sphere of radius  $R$  has positive charge  $+Q$ . Which graph best depicts the electric field as a function of  $r$ , the distance from the center of the sphere?

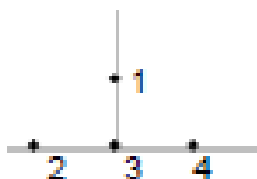


109. Point charges 1 and 2 have equal magnitude. The diagram to above shows the electric field lines surrounding them. Which of the following statements is true?
- (A) Charge 1 is positive, charge 2 is negative.
  - (B) Charge 1 is negative, charge 2 is positive.
  - (C) Both charges 1 and 2 are positive.
  - (D) Both charges 1 and 2 are negative.
  - (E) Both charges 1 and 2 have the same sign, but it is impossible to tell which.

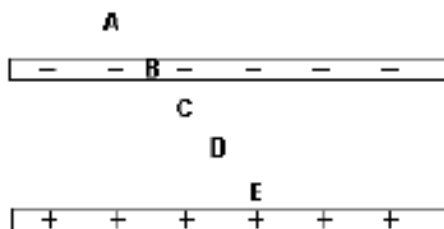


110. A charged rod is placed between two insulated conducting spheres as shown. The spheres have no net charge. Region II has the same polarity as Region
- (A) I only (B) III only (C) IV only (D) I & III only (E) I & IV only
111. Two large oppositely charged insulated plates have a uniform electric field between them. The distance between the plates is increased. Which of the following statements is true?
- I. The field strength decreases.
  - II. The field strength increases.
  - III. The potential difference between the plates increases.
- (A) I only (B) II only (C) III only (D) I and III only (E) II and III only

112. When two charged point-like objects are separated by a distance  $R$ , the force between them is  $F$ . If the distance between them is quadrupled, the force between them is  
 (A)  $16 F$  (B)  $4 F$  (C)  $F$  (D)  $F/4$  (E)  $F/16$
113. An electroscope is given a positive charge, causing its foil leaves to separate. When an object is brought near the top plate of the electroscope, the foils separate even further. We could conclude  
 (A) that the object is positively charged.  
 (B) that the object is electrically neutral.  
 (C) that the object is negatively charged.  
 (D) only that the object is charged.  
 (E) only that the object is uncharged.



114. Four positive point charges are arranged as shown in the accompanying diagram. The force between charges 1 and 3 is  $6.0 \text{ N}$ ; the force between charges 2 and 3 is  $5.0 \text{ N}$ ; and the force between charges 3 and 4 is  $3.0 \text{ N}$ . The magnitude of the total force on charge 3 is most nearly  
 (A)  $6.3 \text{ N}$  (B)  $8.0 \text{ N}$  (C)  $10 \text{ N}$  (D)  $11 \text{ N}$  (E)  $14 \text{ N}$
115. Two isolated parallel plates are separated by a distance  $d$ . They carry opposite charges  $Q$  and each has surface area  $A$ . Which of the following would increase the strength of the electric field between the plates?  
 I. Increasing  $Q$   
 II. Increasing  $A$   
 III. Increasing  $d$   
 (A) I only (B) II only (C) III only (D) I & III only (E) II & III only



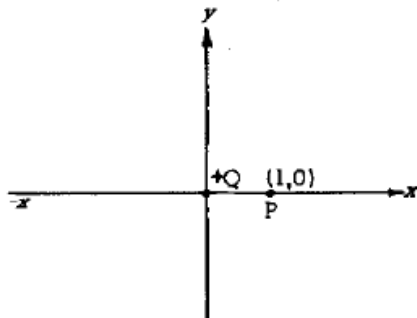
116. Consider the two oppositely charged plates as shown in the diagram. At which of the marked points shown in the diagram would a positively charged particle have the greatest electrical potential energy?  
 (A) A (B) B (C) C (D) D (E) E
117. How much work would be required to move a  $4 \text{ coulomb}$  charge  $6 \text{ meters}$  parallel to a  $24 \text{ N/C}$  electric field?  
 (A)  $0 \text{ J}$  (B)  $24 \text{ J}$  (C)  $96 \text{ J}$  (D)  $144 \text{ J}$  (E)  $576 \text{ J}$
118. When a positive electrically charged glass rod is brought near a neutral hollow metal sphere suspended by an insulating string, the sphere will be attracted to the rod because:  
 (A) the rod is much larger than the sphere  
 (B) the rod removes electron from the sphere  
 (C) the electric charge produces a magnetic field to attract the sphere  
 (D) the charge on the rod causes a separation of charge in the sphere  
 (E) some of the protons from the rod have been given to the sphere



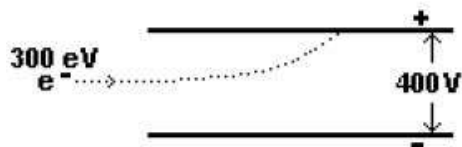
$\alpha^{2+}$   $P^+$



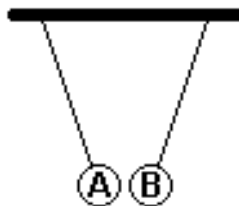
- \*119. An alpha particle and a proton are placed equal distance between two large charged metal plates as shown. Which of the following would best describe the motion of the two particles if they were free to move?
- (A) The alpha particle will travel upwards with twice the velocity of the proton.  
 (B) Both particles will travel upwards with the same velocity.  
 (C) The alpha particle will accelerate upwards with twice the acceleration of the proton.  
 (D) Both particles will accelerate upwards with the same acceleration.  
 (E) The alpha particle will accelerate upwards with half the acceleration of the proton.
120. Two parallel metal plates carry opposite electrical charges each with a magnitude of  $Q$ . The plates are separated by a distance  $d$  and each plate has an area  $A$ . Consider the following:
- I. increasing  $Q$   
 II. increasing  $d$   
 III. increasing  $A$
- Which of the following would have the effect of reducing the potential difference between the plates?
- (A) I only (B) II only (C) III only (D) I and III (E) II and III
121. A positive point charge of  $+q$  and a negative point charge of  $-q$  are separated by a distance  $d$ . What would be the magnitude of the electric field midway between the two charges?
- (A)  $E = 0$  (B)  $E = \frac{kq}{d^2}$  (C)  $E = \frac{2kq}{d^2}$  (D)  $E = \frac{4kq}{d}$  (E)  $E = \frac{8kq}{d^2}$



122. A positive charge  $+Q$  located at the origin produces an electric field  $E_0$  at point P ( $x = +1$ ,  $y = 0$ ). A negative charge  $-2Q$  is placed at such a point as to produce a net field of zero at point P. The second charge will be placed on the
- (A) x-axis where  $x > 1$  (B) x-axis where  $0 < x < 1$  (C) x-axis where  $x < 0$  (D) y-axis where  $y > 0$   
 (E) y-axis where  $y < 0$



123. A 300 eV electron is aimed midway between two parallel metal plates with a potential difference of 400 V. The electron is deflected upwards and strikes the upper plate as shown. What would be the kinetic energy of the electron just before striking the metal plate?
- (A) 360 eV (B) 400 eV (C) 500 eV (D) 700 eV (E) 740 eV



124. Two small hollow metal spheres hung on insulating threads attract one another as shown. It is known that a positively charged rod will attract ball A.

- I. Ball A has a positive charge
- II. Ball B has a negative charge
- III. Ball A and Ball B have opposite charges

Which of the above can be correctly concluded about the charge on the balls?

- (A) I only (B) II only (C) III only (D) all of these (E) none of these

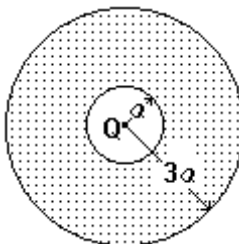
125. A  $5 \times 10^{-6}$  coulomb electric charge is placed midway between two parallel metal plates connected to a 9-volt battery. If the electric charge experiences a force of  $1.5 \times 10^{-4}$  newtons, what is the separation of the metal plates?

- (A)  $6.75 \times 10^{-9}$  m (B)  $2.7 \times 10^{-4}$  m (C)  $3.7 \times 10^{-3}$  m (D) 0.30 m (E) 3.3 m

\*126. A parallel-plate capacitor is connected to a resistanceless circuit with a battery having emf  $\mathcal{E}$  until the capacitor is fully charged. The battery is then disconnected from the circuit and the plates of the capacitor are moved to half of their original separation using insulated gloves. Let  $V_{\text{new}}$  be the potential difference across the capacitor plates when the plates are moved together. Let  $V_{\text{old}}$  be the potential difference across the capacitor plates when

connected to the battery.  $\frac{V_{\text{new}}}{V_{\text{old}}} =$

- (A)  $\frac{1}{4}$  (B)  $\frac{1}{2}$  (C) 1 (D) 2 (E) 4



\*127. A solid, uncharged conducting sphere of radius  $3a$  contains a hollowed spherical region of radius  $a$ . A point charge  $+Q$  is placed at the common center of the spheres. Taking  $V = 0$  as  $r$  approaches infinity, the potential at position  $r = 2a$  from the center of the spheres is:

- (A) 0 (B)  $\frac{2kQ}{3a}$  (C)  $\frac{kQ}{3a}$  (D)  $\frac{kQ}{a}$  (E)  $\frac{kQ}{2a}$

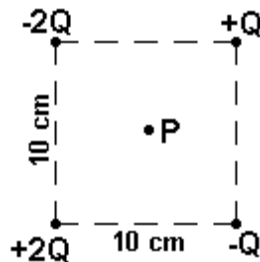
128. Two identical electrical point charges  $Q$ , separated by a distance  $d$  produce an electrical force of  $F$  on one another. If the distance is decreased to a distance of  $0.40d$ , what is the strength of the resulting force?

- (A)  $16F$  (B)  $6.3F$  (C)  $2.5F$  (D)  $0.40F$  (E)  $0.16F$

129. The most convincing proof of the fact that electrical charge comes in a fundamentally-sized basic amount was provided by the work of

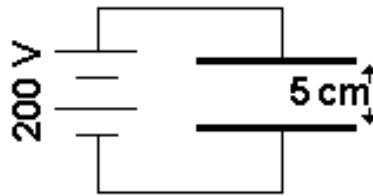
- (A) Crookes (B) Lorentz (C) Rutherford (D) Faraday (E) Millikan





130. Four electrical charges are arranged on the corners of a 10 cm square as shown. What would be the direction of the resulting electric field at the center point P?

(A)  $\rightarrow$  (B)  $\uparrow$  (C)  $\leftarrow$  (D)  $\downarrow$  (E)  $\nearrow$



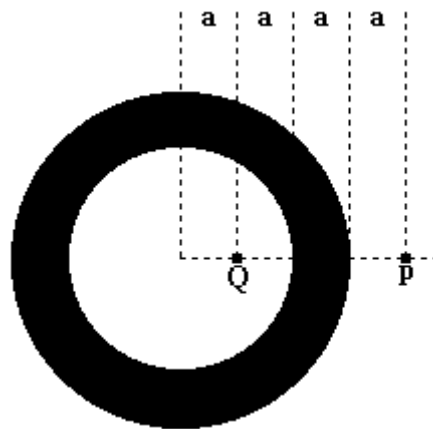
131. A proton is released between the two parallel plates of the fully charged capacitor shown above. What would be the resulting acceleration of the proton?

(A)  $1.0 \times 10^{-7} \text{ m/s}^2$  (B)  $7.3 \times 10^{13} \text{ m/s}^2$  (C)  $9.6 \times 10^8 \text{ m/s}^2$  (D)  $6.3 \times 10^{19} \text{ m/s}^2$  (E)  $3.8 \times 10^{11} \text{ m/s}^2$

132. A circular parallel-plate capacitor is connected to a battery in a circuit. The capacitor is fully charged before the battery is disconnected from the circuit. A uniform material of dielectric constant  $\kappa$  is inserted between the plates of the capacitor, effectively filling the space between the plates. Let  $U_{\text{old}}$  be the energy stored by the capacitor before the dielectric was inserted, while  $U_{\text{new}}$  is the energy stored after the dielectric was inserted.

The ratio of  $U_{\text{new}}/U_{\text{old}}$  is

(A)  $\frac{1}{\kappa^2}$  (B)  $\frac{1}{\kappa}$  (C) 1 (D)  $\kappa$  (E)  $\kappa^2$



- \*133. A solid uncharged conducting sphere has radius  $3a$  contains a hollowed spherical region of radius  $2a$ . A point charge  $+Q$  is placed at a position a distance  $a$  from the common center of the spheres. What is the magnitude of the electric field at the position  $r = 4a$  from the center of the spheres as marked in the figure by P?

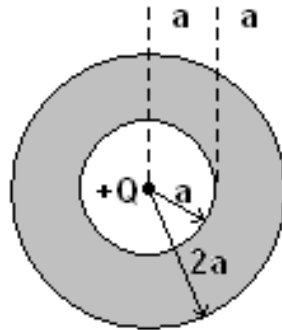
(A) 0 (B)  $\frac{kQ}{16a^2}$  (C)  $\frac{3kQ}{16a^2}$  (D)  $\frac{kQ}{9a^2}$  (E) None of the previous

134. The potential energy of two like charges

- (A) decreases as the charges are separated.
- (B) depends on the sign of the charge.
- (C) is proportional to the square of the relative speed.
- (D) is inversely proportional to the square of the separation.
- (E) is repulsive.

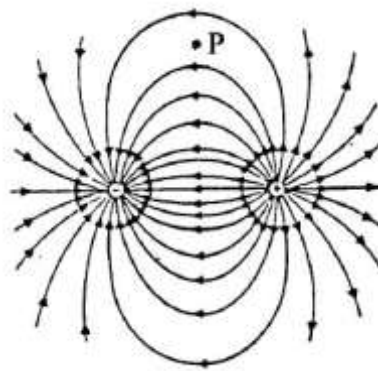
135. A positively charged object is brought near but not in contact with the top of an uncharged gold leaf electroscope. The experimenter then briefly touches the electroscope with a finger. The finger is removed, followed by the removal of the positively charged object. What happens to the leaves of the electroscope when a negative charge is now brought near but not in contact with the top of the electroscope?

- (A) they remain uncharged
- (B) they move farther apart
- (C) they move closer together
- (D) they remain positively charged but unmoved
- (E) they remain negatively charged but unmoved



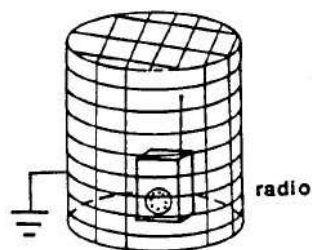
\*136. A solid spherical conducting shell has inner radius  $a$  and outer radius  $2a$ . At the center of the shell is located a point charge  $+Q$ . What must the excess charge of the shell be in order for the charge density on the inner and outer surfaces of the shell to be exactly equal?

- (A)  $-5Q$  (B)  $+3Q$  (C)  $-4Q$  (D)  $+4Q$  (E)  $-3Q$

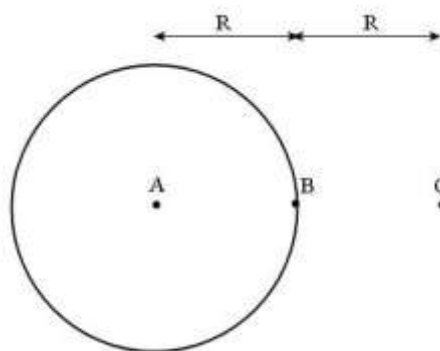


137. A small positive test charge is placed at point P in the region near two charges. Which of the following arrows indicates the direction of the force on the positive test charge?

- (A)
- (B)
- (C)
- (D)
- (E)

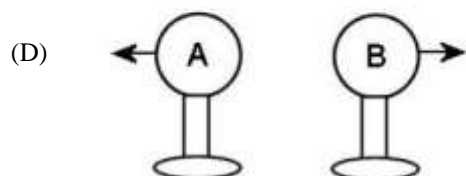
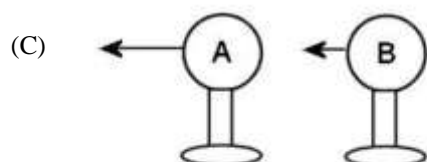
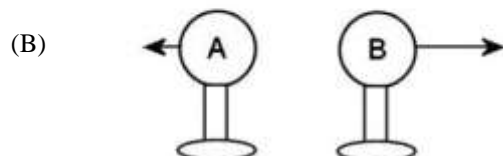
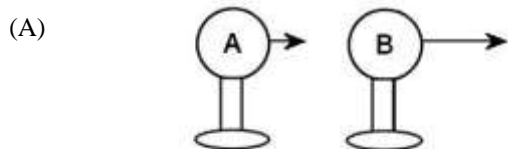


138. A portable radio that is playing is placed inside a screen cage as shown. When inside the cage the radio stops playing because
- (A) the electric potential of the batteries is neutralized.
  - (B) the charge on the radio is zero.
  - (C) the sound cannot travel through the cage.
  - (D) the electric field of the radio waves cannot penetrate the cage.
  - (E) none of the above reasons.



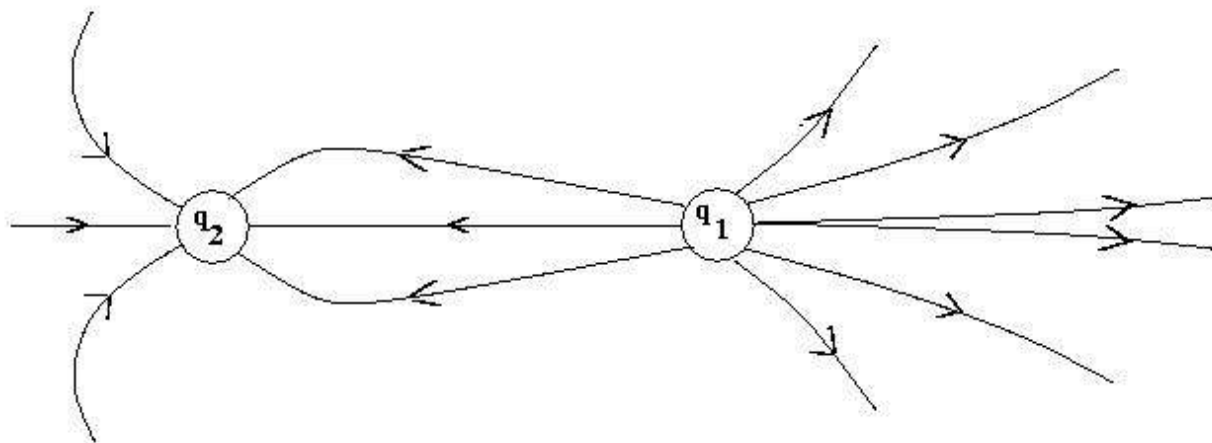
139. A spherical conducting shell has a net charge  $+Q$  placed on it. Which of the following is the correct relationship for the electric potential at the points labeled A, B, and C? Point A is at the center of the sphere, point B is at the surface of the shell, a distance  $R$  from point A, and point C is a distance  $R$  from point B outside the sphere. As  $r$  goes to infinity,  $V = 0$ .
- (A)  $V_C < V_B < V_A$
  - (B)  $V_A < V_B < V_C$
  - (C)  $V_C = V_B = V_A$
  - (D)  $V_C = V_B < V_A$
  - (E)  $V_C < V_B = V_A$
140. Which statement about a system of point charges that are fixed in space is necessarily true?
- (A) If the potential energy of the system is negative, net positive work by an external agent is required to take the charges in the system back to infinity.
  - (B) If the potential energy of the system is positive, net positive work is required to bring any new charge not part of the system in from infinity to its final resting location.
  - (C) If the potential energy of the system is zero, no negative charges are in the configuration.
  - (D) If the potential energy of the system is negative, net positive work by an external agent was required to assemble the system of charges.
  - (E) If the potential energy of the system is zero, then there is no electric force anywhere in space on any other charged particle not part of the system.
141. A positive point charge exerts a force of magnitude  $F$  on a negative point charge placed a distance  $x$  away. If the distance between the two point charges is halved, what is the magnitude of the new force that the positive point charge exerts on the negative point charge?
- (A)  $4F$
  - (B)  $2F$
  - (C)  $F$
  - (D)  $F/2$
  - (E)  $F/4$

142. Two uniformly charged non-conducting spheres on insulating bases are placed on an air table. Sphere A has a charge  $+3Q$  coulombs and sphere B has a charge  $+Q$  coulombs. Which of the following correctly illustrates the magnitude and direction of the electrostatic force between the spheres when they are released?



(E) None of the above

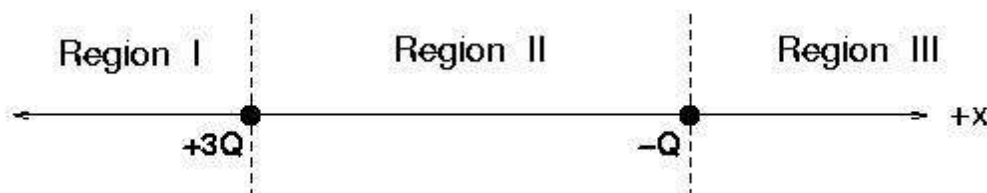
143. For the diagram shown below, what is the ratio of the charges  $q_2/q_1$  where the diagram shown has a representation of the field lines in the space near the charges.



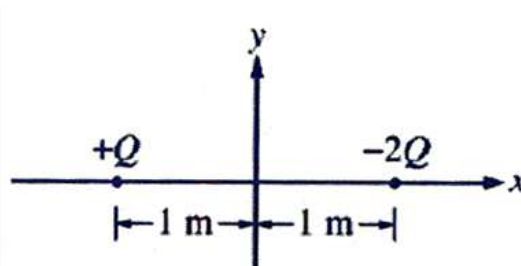
(A)  $-3/2$  (B)  $-2/3$  (C)  $2/3$  (D)  $3/2$  (E) 1

Questions 144 – 145

Two point charges are fixed on the  $x$ -axis in otherwise empty space as shown below.

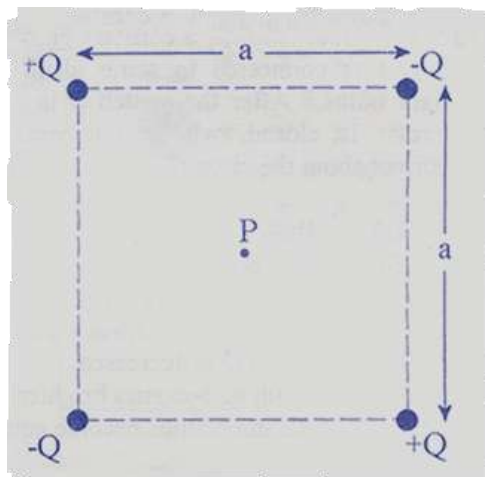


144. In which Region(s) is there a place on the  $x$ -axis (aside from infinity) at which the electric potential is equal to zero?
- (A) Only in Region II                      (D) In both Regions I and III  
 (B) Only in Region III                    (E) In both Regions II and III  
 (C) In both Regions I and II
145. In which Region(s) is there a place on the  $x$ -axis (aside from infinity) at which the electric field is equal to zero?
- (A) Only in Region II                      (D) In both Regions I and III  
 (B) Only in Region III                    (E) In both Regions II and III  
 (C) In both Regions I and II
146. A parallel-plate capacitor is connected to a battery. Without disconnecting the capacitor, a student pulls the capacitor's plates apart so that the plate separation doubles. As a result of this action, what happens to the voltage across the capacitor and the energy stored by the capacitor?
- (A) the voltage doubles; the energy stays the same  
 (B) the voltage halves; the energy doubles  
 (C) the voltage doubles; the energy halves  
 (D) the voltage stays the same; the energy halves  
 (E) the voltage stays the same; the energy doubles
147. A person rubs a neutral comb through their hair and the comb becomes negatively charged. Which of the following is the best explanation for this phenomenon?
- (A) The hair gains protons from the comb.  
 (B) The hair gains protons from the comb while giving electrons to the comb.  
 (C) The hair loses electrons to the comb.  
 (D) The comb loses protons to the person's hand holding the comb.  
 (E) The comb loses protons to the person's hand while also gaining electrons from the hair.



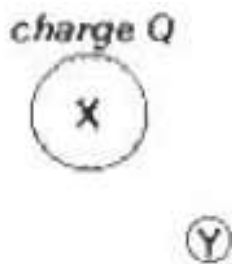
148. A charge of  $+Q$  is located on the  $x$ -axis at  $x = -1$  meter and a charge of  $-2Q$  is held at  $x = +1$  meter, as shown in the diagram above. At what position on the  $x$ -axis will a test charge of  $+q$  experience a zero net electrostatic force?
- (A)  $-(3 + \sqrt{8})$  m    (B)  $-1/3$  m    (C) 0    (D)  $1/3$  m    (E)  $(3 + \sqrt{8})$  m

149. The two plates of a parallel-plate capacitor are a distance  $d$  apart and are mounted on insulating supports. A battery is connected across the capacitor to charge it and is then disconnected. The distance between the insulated plates is then increased to  $2d$ . If fringing of the field is still negligible, which of the following quantities is doubled?
- (A) The capacitance of the capacitor
  - (B) The total charge on the capacitor
  - (C) The surface density of the charge on the plates of the capacitor
  - (D) The energy stored in the capacitor
  - (E) The intensity of the electric field between the plates of the capacitor

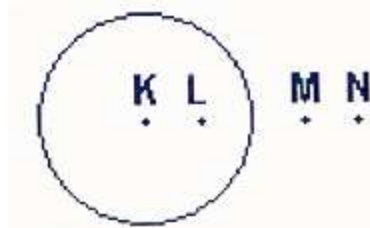


150. Four point charges are each brought from infinity into a region of empty space and are "attached in place" into a square arrangement of side length  $a$  as shown below. The location marked  $P$  is at the center of the square and has no charge associated with it. Which is a true statement about the configuration of charges?
- (A) The net electric field at point  $P$  is directed to the left.
  - (B) The net electric field at point  $P$  is directed to the right.
  - (C) The total force on each charge from the other three in the configuration is zero.
  - (D) The electric potential at the point  $P$  is  $\frac{\sqrt{2}Q}{\pi\epsilon_0 a}$
  - (E) The outside agent that assembled the charges did negative net work.
151. Two point objects each carrying charge  $10Q$  are separated by a distance  $d$ . The force between them is  $F$ . If half the charge on one object is transferred to the other object while at the same time the distance between them is doubled, what is the new force between the two objects?
- (A)  $0.19 F$  (B)  $0.25 F$  (C)  $0.75 F$  (D)  $4.0 F$  (E) no change in  $F$
152. A parallel plate capacitor is charged to a voltage  $V$ . To double the energy stored on the capacitor, what would the voltage between the plates have to become?
- (A)  $0.25 V$  (B)  $0.50 V$  (C)  $1.4 V$  (D)  $2.0 V$  (E)  $4.0 V$

153. Two identical spheres carry identical electric charges. If the spheres are set a distance  $d$  apart they repel one another with a force  $F$ . A third sphere, identical to the other two but initially uncharged is then touched to one sphere and then to the other before being removed. What would be the resulting force between the original two spheres?  
 (A)  $\frac{3}{4} F$  (B)  $\frac{5}{8} F$  (C)  $\frac{1}{2} F$  (D)  $\frac{3}{8} F$  (E)  $\frac{1}{4} F$
154. Two parallel metal plates 0.04 meters apart are connected to a 1.5 volt battery. When fully charged, each metal plate has a charge of magnitude  $9.0 \times 10^{-4}$  coulombs. What is the capacitance of the two plates?  
 (A)  $1.5 \times 10^{-2} \text{ F}$  (B)  $1.2 \times 10^{-3} \text{ F}$  (C)  $3.0 \times 10^{-4} \text{ F}$  (D)  $6.0 \times 10^{-4} \text{ F}$  (E)  $9.0 \times 10^{-4} \text{ F}$
155. An alpha particle is accelerated to a velocity  $v$  in a particle accelerator by a potential difference of 1200 V. Which of the following potential differences would be needed to give the alpha particle twice the velocity?  
 (A) 7200 V (B) 4800 V (C) 4100 V (D) 2400 V (E) 1700 V
156. An electrical charge  $Q$  is placed at one vertex of an equilateral triangle. When an identical charge is placed at another vertex, each charge feels a force of 15 N. When a third charge identical to the first two, is placed at the third vertex, what would be the magnitude of the force on each charge?  
 (A) 15 N (B) 26 N (C) 30 N (D) 42 N (E) 45 N
157. Two conducting spheres with the same charge  $Q$  are separated by an infinite distance. Sphere A has a radius of 10 cm while sphere B has a radius of 20 cm. At what distance from the centers of the spheres would the magnitude of the electric field be the same?  
 (A) 15 cm from A and 15 cm from B (B) 20 cm from A and 34 cm from B  
 (C) 20 cm from A and 40 cm from B (D) 30 cm from A and 40 cm from B  
 (E) 40 cm from A and 40 cm from B

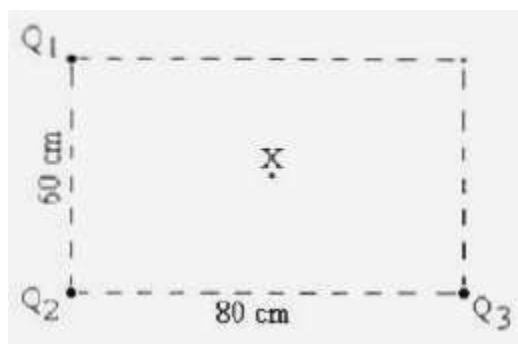


- \*158. A large conducting sphere labeled X contains an electrical charge  $Q$ . Sphere X is connected by a metal wire to a small uncharged conducting sphere labeled Y. The wire is then removed. How does the electrical field ( $E_y$ ) at the surface of sphere Y compare to the electrical field ( $E_x$ ) at the surface of sphere X?  
 (A)  $E_y = 0$  (B)  $E_y = E_x$  (C)  $E_y < E_x$  (D)  $E_y > E_x$  (E)  $E_x = 0$
159. What voltage would be required across a 8.9 nF capacitor to accumulate  $1.5 \times 10^{12}$  excess electrons on one plate of the capacitor?  
 (A) 0.17 V (B) 3.7 V (C) 5.9 V (D) 14 V (E) 27 V



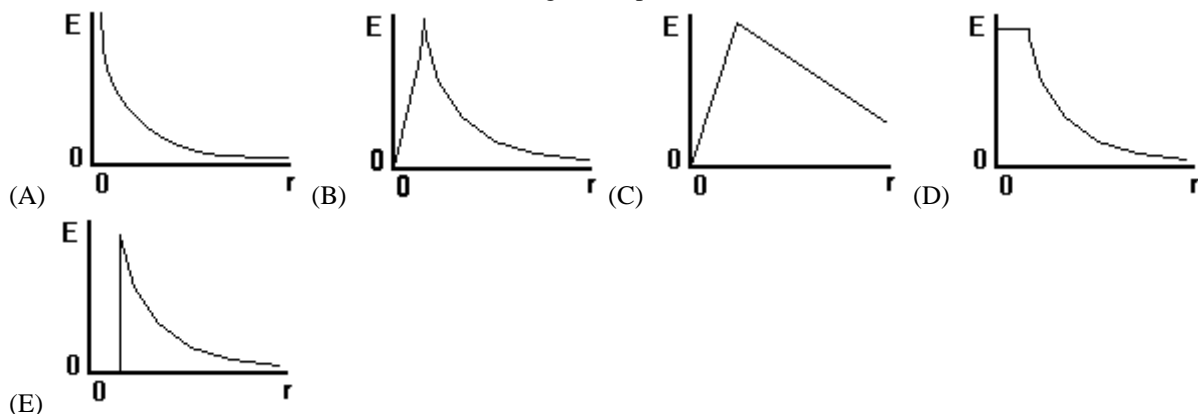
160. A hollow metal sphere is uniformly charged with positive charge. Points K and L are inside the sphere and points M and N are outside the sphere as shown in the diagram. At which point would the field be the smallest?  
 (A) points K and N (B) points L and M (C) points K and L (D) points M and N (E) point K only
161. Two circular metal plates, each having an area  $A$  are placed to one another a distance  $d$  apart. When a potential difference is applied across the two plates, an electric field  $E$  is measured halfway between the two plates at their centers. What is the magnitude of the potential difference between the two plates?  
 (A)  $Ed$  (B)  $E/d$  (C)  $EA/d$  (D)  $Ed/A$  (E)  $EA$

Questions 162 – 163

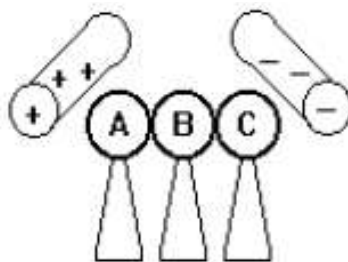


Three electric charges ( $Q_1$ ,  $Q_2$ , and  $Q_3$ ) are arranged at three corners of a rectangle as shown in the diagram and each has a charge of  $-40 \text{ nC}$ .

162. What is the magnitude of the net force on  $Q_2$ ?  
 (A)  $1.4 \times 10^{-5} \text{ N}$  (B)  $1.7 \times 10^{-5} \text{ N}$  (C)  $4.2 \times 10^{-5} \text{ N}$  (D)  $4.6 \times 10^{-5} \text{ N}$  (E)  $1.47 \times 10^{-4} \text{ N}$
163. What would be the magnitude of the total electric field at center point  $X$ ?  
 (A)  $1440 \text{ N/C}$  (B)  $720 \text{ N/C}$  (C)  $360 \text{ N/C}$  (D)  $180 \text{ N/C}$  (E)  $90 \text{ N/C}$
164. Which of the following graphs would best represent the electric field of a hollow Van de Graaff sphere as a function of distance from its center when it is charged to a potential of 400,000 volts?



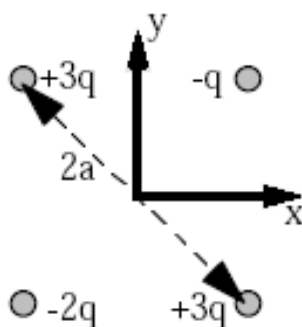
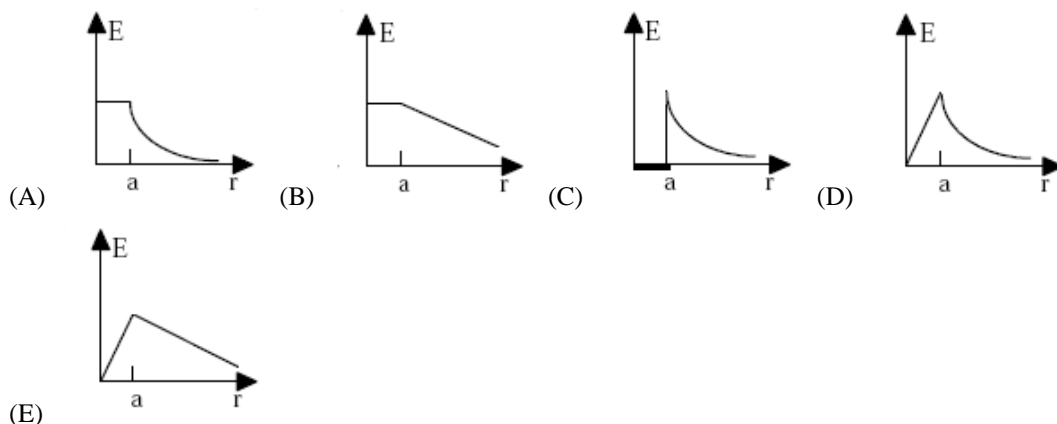




165. Three metal spheres A, B, and C are mounted on insulating stands. The spheres are touching one another, as shown in the diagram below. A strong positively charged object is brought near sphere A and a strong negative charge is brought near sphere C. While the charged objects remain near spheres A and C, sphere B is removed by means of its insulating stand. After the charged objects are removed, sphere B is first touched to sphere A and then to sphere C. The resulting charge on B would be of what relative amount and sign?

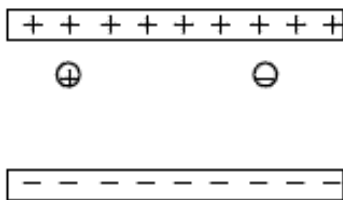
- (A) the same sign but  $1/2$  the magnitude as originally on sphere A
- (B) the opposite sign but  $1/2$  the magnitude as originally on sphere A
- (C) the opposite sign but  $1/4$  the magnitude as originally on sphere A
- (D) the same sign but  $1/2$  the magnitude as originally on sphere C
- (E) neutrally charged

166. A charge is uniformly distributed through a volume of radius  $a$ . Which of the graphs below best represents the magnitude of the electric field as a function of distance from the center of the sphere?



167. Four point charges are placed at the corners of a square with diagonal  $2a$  as shown in the diagram. What is the total electric field at the center of the square?

- (A)  $kq/a^2$  at an angle  $45^\circ$  above the  $+x$  axis.
- (B)  $kq/a^2$  at an angle  $45^\circ$  below the  $-x$  axis.
- (C)  $3kq/a^2$  at an angle  $45^\circ$  above the  $-x$  axis.
- (D)  $3kq/a^2$  at an angle  $45^\circ$  below the  $+x$  axis.
- (E)  $9kq/a^2$  at an angle  $45^\circ$  above the  $+x$  axis.

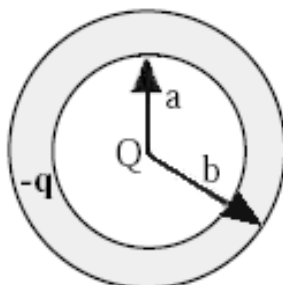


168. A free electron and a free proton are placed between two oppositely charged parallel plates. Both are closer to the positive plate than the negative plate. See the diagram below. Which of the following statements is true?

- I. The force on the proton is greater than the force on the electron.
- II. The potential energy of the proton is greater than that of the electron.
- III. The potential energy of the proton and the electron is the same.

(A) I only (B) II only (C) III only (D) I & II only (E) I & III only

#### Questions 169 – 170



A spherical shell with an inner surface of radius  $a$  and an outer surface of radius  $b$  is made of conducting material. A charge  $+Q$  is placed at the center of the spherical shell and a total charge  $-q$  is placed on the shell.

\*169. How is the charge  $-q$  distributed after it has reached equilibrium?

- (A)  $+Q$  on the inner surface,  $-q - Q$  on the outer surface.
- (B) The charge  $-q$  is spread uniformly between the inner and outer surface.
- (C)  $-Q$  on the inner surface,  $-q + Q$  on the outer surface.
- (D)  $-Q$  on the inner surface,  $-q$  on the outer surface.
- (E) Zero charge on the inner surface,  $-q$  on the outer surface.

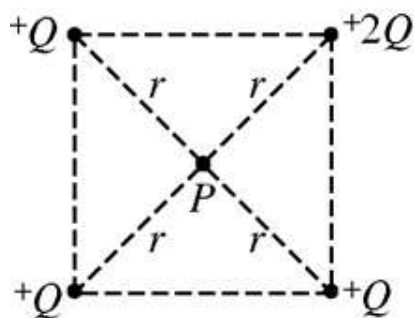
\*170. What is the electrostatic potential at a distance  $R$  from the center of the shell, where  $b < R < a$ ?

- (A) 0 (B)  $kQ/a$  (C)  $kQ/R$  (D)  $k(Q - q)/R$  (E)  $k(Q - q)/b$

171. Conducting sphere  $X$  is initially uncharged. Conducting sphere  $Y$  has twice the diameter of sphere  $X$  and initially has charge  $q$ . If the spheres are connected by a long thin wire, which of the following is true once equilibrium has been reached?

- (A) Sphere  $Y$  has half the potential of sphere  $X$ .
- (B) Spheres  $X$  and  $Y$  have the same potential.
- (C) Sphere  $Y$  has twice the potential of sphere  $X$ .
- (D) Sphere  $Y$  has half the charge of sphere  $X$ .
- (E) Spheres  $X$  and  $Y$  have the same charge.

Questions 172 – 173



Four positive charges are fixed at the corners of a square, as shown above. Three of the charges have magnitude  $Q$ , and the fourth charge has a magnitude  $2Q$ . Point  $P$  is at the center of the square at a distance  $r$  from each charge.

172. What is the electric potential at point  $P$ ?

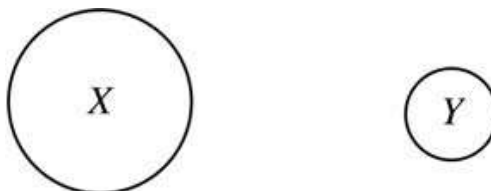
- (A) Zero (B)  $kQ/r$  (C)  $2kQ/r$  (D)  $4kQ/r$  (E)  $5kQ/r$

173. What is the magnitude of the electric field at point  $P$ ?

- (A) Zero (B)  $kQ/r^2$  (C)  $2kQ/r^2$  (D)  $4kQ/r^2$  (E)  $5kQ/r^2$

174. If the separation between the plates of an isolated charged parallel-plate capacitor is increased slightly, which of the following also increases?

- (A) The capacitance  
(B) The stored electrostatic energy  
(C) The force of attraction between the plates  
(D) The magnitude of the charge on each plate  
(E) The magnitude of the electric field in the region between the plates



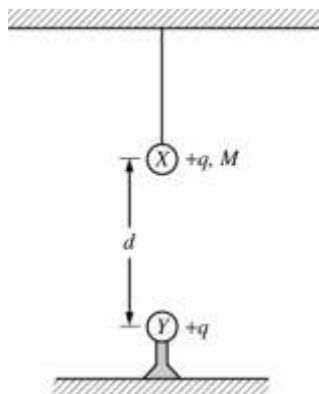
175. The two charged metal spheres  $X$  and  $Y$  shown above are far apart, and each is isolated from all other charges.

The radius of sphere  $X$  is greater than that of sphere  $Y$ , and the magnitudes of the electric fields just outside their surfaces are the same. How does the charge on sphere  $X$  compare with that on sphere  $Y$ ?

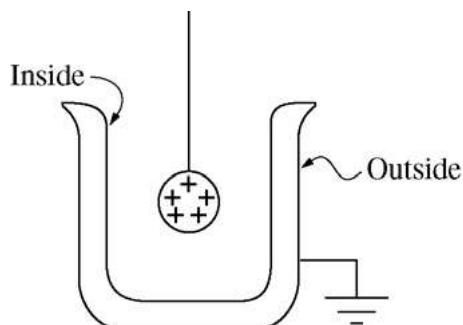
- (A) It is greater.  
(B) It is less.  
(C) It is the same.  
(D) It cannot be determined without knowing the actual radii of the spheres.  
(E) It cannot be determined without knowing the actual value of the electric field just outside the spheres.

176. Two negative point charges are a distance  $x$  apart and have potential energy  $U$ . If the distance between the point charges increases to  $3x$ , what is their new potential energy?

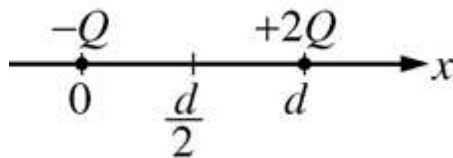
- (A)  $9U$  (B)  $3U$  (C)  $U$  (D)  $1/3 U$  (E)  $1/9 U$



177. Sphere X of mass  $M$  and charge  $+q$  hangs from a string as shown above. Sphere Y has an equal charge  $+q$  and is fixed in place a distance  $d$  directly below sphere X. If sphere X is in equilibrium, the tension in the string is most nearly
- (A)  $Mg$    (B)  $Mg + kq/d$    (C)  $Mg - kq/d$    (D)  $Mg + kq^2/d^2$    (E)  $Mg - kq^2/d^2$

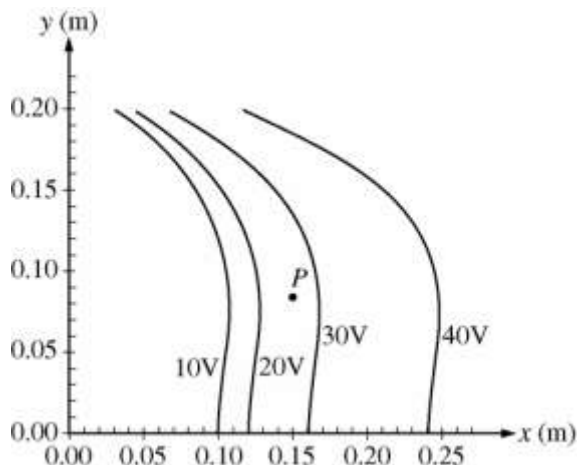


178. A small positively charged sphere is lowered by a nonconducting thread into a grounded metal cup without touching the inside surface of the cup, as shown above. The grounding wire attached to the outside surface is disconnected and the charged sphere is then removed from the cup. Which of the following best describes the subsequent distribution of excess charge on the surface of the cup?
- (A) Negative charge resides on the inside surface, and no charge resides on the outside surface.  
 (B) Negative charge resides on the outside surface, and no charge resides on the inside surface.  
 (C) Positive charge resides on the inside surface, and no charge resides on the outside surface.  
 (D) Positive charge resides on the outside surface, and no charge resides on the inside surface.  
 (E) Negative charge resides on the inside surface, and positive charge resides on the outside surface.
179. A helium nucleus (charge  $+2q$  and mass  $4m$ ) and a lithium nucleus (charge  $+3q$  and mass  $7m$ ) are accelerated through the same electric potential difference,  $V_0$ . What is the ratio of their resultant kinetic energies,  $\frac{K_{\text{lithium}}}{K_{\text{helium}}}$ ?
- (A)  $2/3$    (B)  $6/7$    (C)  $1$    (D)  $7/6$    (E)  $3/2$



180. A point charge  $-Q$  is located at the origin, while a second point charge  $+2Q$  is located at  $x = d$  on the  $x$ -axis, as shown above. A point on the  $x$ -axis where the net electric field is zero is located in which of the following regions?
- (A)  $-\infty < x < 0$    (B)  $0 < x < d/2$    (C)  $d/2 < x < d$    (D)  $d < x < \infty$    (E) No region on the  $x$ -axis

Questions 181 – 182



A fixed charge distribution produces the equipotential lines shown in the figure above.

181. Which of the following expressions best represents the magnitude of the electric field at point  $P$  ?

- (A)  $10 \text{ V}/0.14 \text{ m}$  (B)  $10 \text{ V}/0.04 \text{ m}$  (C)  $25 \text{ V}/0.14 \text{ m}$  (D)  $25 \text{ V}/0.04 \text{ m}$  (E)  $40 \text{ V}/0.25 \text{ m}$

182. The direction of the electric field at point  $P$  is most nearly

- (A) toward the left  
(B) toward the right  
(C) toward the bottom of the page  
(D) toward the top of the page  
(E) perpendicular to the plane of the page

Questions 183 – 184

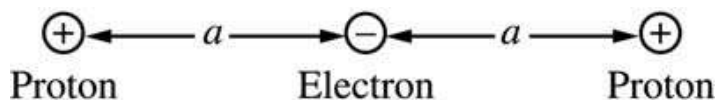
A cloud contains spherical drops of water of radius  $R$  and charge  $Q$ . Assume the drops are far apart.

183. The electric field  $E_0$  and potential  $V_0$  at the surface of each drop is given by which of the following?

- |     |          |          |
|-----|----------|----------|
|     | $E_0$    | $V_0$    |
| (A) | 0        | 0        |
| (B) | $kQ/R$   | $kQ/R^2$ |
| (C) | $kQ/R^2$ | $kQ/R$   |
| (D) | 0        | $kQ/R$   |
| (E) | $kQ/R$   | 0        |

\*184. If two droplets happen to combine into a single larger droplet, the new potential  $V$  at the surface of the larger droplet is most nearly equal to

- (A)  $3V_0$  (B)  $2V_0$  (C)  $\frac{2}{\sqrt{3}}V_0$  (D)  $\sqrt[3]{2}V_0$  (E)  $V_0$



185. Two protons and an electron are assembled along a line, as shown above. The distance between the electron and each proton is  $a$ . What is the work done by an external force in assembling this configuration of charges?

- (A)  $-2ke^2/a$  (B)  $-3ke^2/2a$  (C)  $ke^2/2a$  (D)  $3ke^2/2a$  (E)  $3ke^2/a$

186. A conducting sphere with a radius of 0.10 meter has  $1.0 \times 10^{-9}$  coulomb of charge deposited on it. The electric field just outside the surface of the sphere is
- (A) zero    (B) 450 V/m    (C) 900 V/m    (D) 4,500 V/m    (E) 90,000 V/m